



US009182034B2

(12) **United States Patent**
Long et al.

(10) **Patent No.:** **US 9,182,034 B2**
(45) **Date of Patent:** **Nov. 10, 2015**

(54) **MODULATION CONTROL SYSTEM AND METHOD FOR A HYBRID TRANSMISSION**

(71) Applicant: **Allison Transmission, Inc.,**
Indianapolis, IN (US)

(72) Inventors: **Charles F. Long**, Pittsboro, IN (US);
Charles T. Taylor, Indianapolis, IN (US)

(73) Assignee: **Allison Transmission, Inc.,**
Indianapolis, IN (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 213 days.

(21) Appl. No.: **13/846,971**

(22) Filed: **Mar. 19, 2013**

(65) **Prior Publication Data**

US 2013/0213501 A1 Aug. 22, 2013

Related U.S. Application Data

(63) Continuation of application No.
PCT/US2012/025457, filed on Feb. 16, 2012.

(60) Provisional application No. 61/443,750, filed on Feb. 17, 2011.

(51) **Int. Cl.**
F16H 61/00 (2006.01)
B60K 6/48 (2007.10)
(Continued)

(52) **U.S. Cl.**
CPC **F16H 61/0031** (2013.01); **B60K 6/12**
(2013.01); **B60K 6/20** (2013.01); **B60K 6/48**
(2013.01); **F16D 25/14** (2013.01); **F16H**
61/0021 (2013.01); **F16H 61/0206** (2013.01);
B60Y 2200/92 (2013.01); **Y02T 10/6221**
(2013.01); **Y10S 903/902** (2013.01);
(Continued)

(58) **Field of Classification Search**

CPC F16H 61/0031

USPC 477/15

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2,374,822 A 5/1945 Claire
3,025,718 A * 3/1962 Christenson 477/109

(Continued)

FOREIGN PATENT DOCUMENTS

DE 3519026 4/1986
DE 10 2005 015911 A1 10/2006

(Continued)

OTHER PUBLICATIONS

European Supplemental Search Report for European Patent Application No. 12757971.2 dated Aug. 4, 2014.

(Continued)

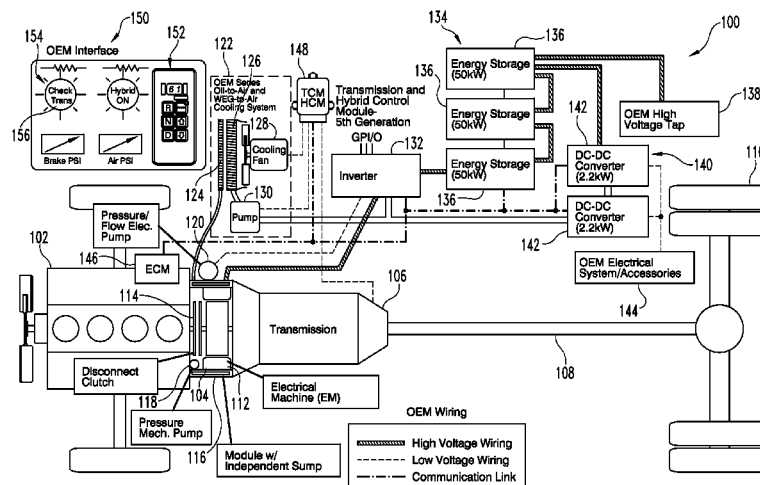
Primary Examiner — Tisha Lewis

(74) *Attorney, Agent, or Firm* — Woodard Emhardt Moriarty
McNett & Henry LLP

(57) **ABSTRACT**

A hydraulic system includes a main modulation control scheme which relies in part on the use of a VBS solenoid and the multiplexing of that solenoid. The hydraulic system is associated with a hybrid module and by controlling the main pressure at a reduced level, the fuel economy and reliability of that hybrid module are improved. The system pressure is controlled by the multiplexed VBS solenoid in order to maintain adequate clutch pressure based on torque requirements. The overall system cost is reduced by the multiplexing of valves and solenoids.

29 Claims, 24 Drawing Sheets



- (51) **Int. Cl.**
B60K 6/12 (2006.01)
B60K 6/20 (2007.10)
F16H 61/02 (2006.01)
F16D 48/02 (2006.01)
- (52) **U.S. Cl.**
CPC *Y10S 903/903* (2013.01); *Y10T 137/8593*
(2015.04); *Y10T 137/85986* (2015.04); *Y10T*
137/86131 (2015.04)
- (56) **References Cited**
- U.S. PATENT DOCUMENTS
- | | | | | | | | |
|-----------|------|---------|--------------------------------|--------------|------|---------|--------------------------|
| 3,800,913 | A | 4/1974 | Schmitt | 7,543,695 | B2 | 6/2009 | Redelman et al. |
| 3,863,739 | A | 2/1975 | Schaefer et al. | 7,556,120 | B2 | 7/2009 | Sah et al. |
| 4,584,487 | A | 4/1986 | Hesse et al. | 7,558,699 | B2 | 7/2009 | Beck et al. |
| 4,838,126 | A | 6/1989 | Wilfinger et al. | 7,651,427 | B2 | 1/2010 | Long et al. |
| 5,019,757 | A | 5/1991 | Beifus | 7,779,958 | B2 | 8/2010 | Kitano et al. |
| 5,121,714 | A | 6/1992 | Susa et al. | 7,946,389 | B2 | 5/2011 | Kakinami et al. |
| 5,209,110 | A | 5/1993 | Sano et al. | 2002/0177960 | A1 | 11/2002 | Berndorfer |
| 5,217,085 | A | 6/1993 | Barrie et al. | 2003/0059310 | A1 | 3/2003 | Koenig et al. |
| 5,347,821 | A | 9/1994 | Oltman et al. | 2004/0192502 | A1 | 9/2004 | Suzuki et al. |
| 5,362,206 | A | 11/1994 | Westerman et al. | 2005/0031443 | A1 | 2/2005 | Ohlsson et al. |
| 5,415,603 | A | 5/1995 | Tuzuki et al. | 2007/0173373 | A1 | 7/2007 | Kinugasa et al. |
| 5,447,414 | A | 9/1995 | Nordby et al. | 2007/0240919 | A1 | 10/2007 | Carlson |
| 5,606,946 | A | 3/1997 | Data et al. | 2008/0017472 | A1 | 1/2008 | Redelman et al. |
| 5,669,464 | A | 9/1997 | Earleson | 2008/0067116 | A1 | 3/2008 | Anderson et al. |
| 5,736,823 | A | 4/1998 | Nordby et al. | 2008/0121464 | A1 | 5/2008 | Ledger |
| 5,752,482 | A | 5/1998 | Roettgen et al. | 2008/0260541 | A1 | 10/2008 | Lifson et al. |
| 5,823,282 | A | 10/1998 | Yamaguchi | 2009/0014245 | A1 | 1/2009 | Shevchenko et al. |
| 5,895,099 | A | 4/1999 | Diecke et al. | 2009/0107755 | A1 | 4/2009 | Kothari et al. |
| 5,944,632 | A | 8/1999 | Hara et al. | 2009/0116155 | A1 | 5/2009 | Almalki et al. |
| 6,172,602 | B1 | 1/2001 | Hasfjord | 2009/0118878 | A1 | 5/2009 | Park |
| 6,209,672 | B1 * | 4/2001 | Severinsky 180/65.23 | 2009/0235657 | A1 | 9/2009 | Rampen et al. |
| 6,244,825 | B1 | 6/2001 | Sasaki et al. | 2009/0247353 | A1 * | 10/2009 | Tryon et al. 477/20 |
| 6,292,731 | B1 * | 9/2001 | Kirchhoffer et al. 701/55 | 2009/0247355 | A1 * | 10/2009 | Tryon et al. 477/52 |
| 6,305,664 | B1 * | 10/2001 | Holmes et al. 251/129.18 | 2009/0253552 | A1 * | 10/2009 | Foster 477/130 |
| 6,390,947 | B1 | 5/2002 | Aoki et al. | 2009/0276119 | A1 | 11/2009 | Barker et al. |
| 6,527,074 | B1 | 3/2003 | Morishita | 2010/0083730 | A1 | 4/2010 | Le et al. |
| 6,607,142 | B1 | 8/2003 | Boggs et al. | 2010/0125023 | A1 | 5/2010 | List et al. |
| 6,638,022 | B2 | 10/2003 | Shimabukuro et al. | 2010/0229824 | A1 | 9/2010 | Matsuo et al. |
| 6,647,326 | B2 | 11/2003 | Nakamori et al. | 2010/0332089 | A1 | 12/2010 | Gianone et al. |
| 6,716,138 | B2 | 4/2004 | Matsubara et al. | 2011/0039657 | A1 | 2/2011 | Gibson et al. |
| 7,041,030 | B2 | 5/2006 | Kuroda et al. | | | | |
| 7,082,758 | B2 | 8/2006 | Kageyama et al. | | | | |
| 7,117,120 | B2 | 10/2006 | Beck et al. | | | | |
| 7,168,924 | B2 | 1/2007 | Beck et al. | | | | |
| 7,174,876 | B2 | 2/2007 | Suzuki et al. | | | | |
| 7,192,518 | B2 | 3/2007 | Roesgen | | | | |
| 7,255,214 | B2 | 8/2007 | Long et al. | | | | |
| 7,285,066 | B2 | 10/2007 | Long et al. | | | | |
| 7,288,039 | B2 | 10/2007 | Foster et al. | | | | |
| 7,396,306 | B2 | 7/2008 | Long et al. | | | | |
| 7,427,914 | B2 | 9/2008 | Plantamura | | | | |
| 7,481,053 | B2 | 1/2009 | Kitano et al. | | | | |
- FOREIGN PATENT DOCUMENTS
- | | | | |
|----|----------------|----|---------|
| DE | 10 2007 004964 | A1 | 8/2008 |
| EP | 0515326 | | 11/1992 |
| GB | 1471305 | | 4/1977 |
| GB | 2 046 376 | A | 11/1980 |
| GB | 2402720 | | 2/2007 |
| JP | 56-003307 | A | 1/1981 |
| JP | 2000337119 | A | 5/2000 |
| JP | 2004-067001 | | 3/2004 |
| KR | 2005038168 | | 4/2005 |
| KR | 10-1039579 | B1 | 6/2011 |
- OTHER PUBLICATIONS
- International Search Report and Written Opinion issued in PCT/
US2012/024119, dated Aug. 22, 2012.
- International Search Report and Written Opinion issued in PCT/
US2012/025451, dated Aug. 27, 2012.
- International Search Report and Written Opinion issued in PCT/
US2012/025457, dated Dec. 26, 2012.
- International Search Report and Written Opinion issued in PCT/
US2012/027847, mailed Sep. 26, 2012.
- International Search Report and Written Opinion issued in PCT/
US2012/043432, dated Oct. 23, 2012.
- * cited by examiner

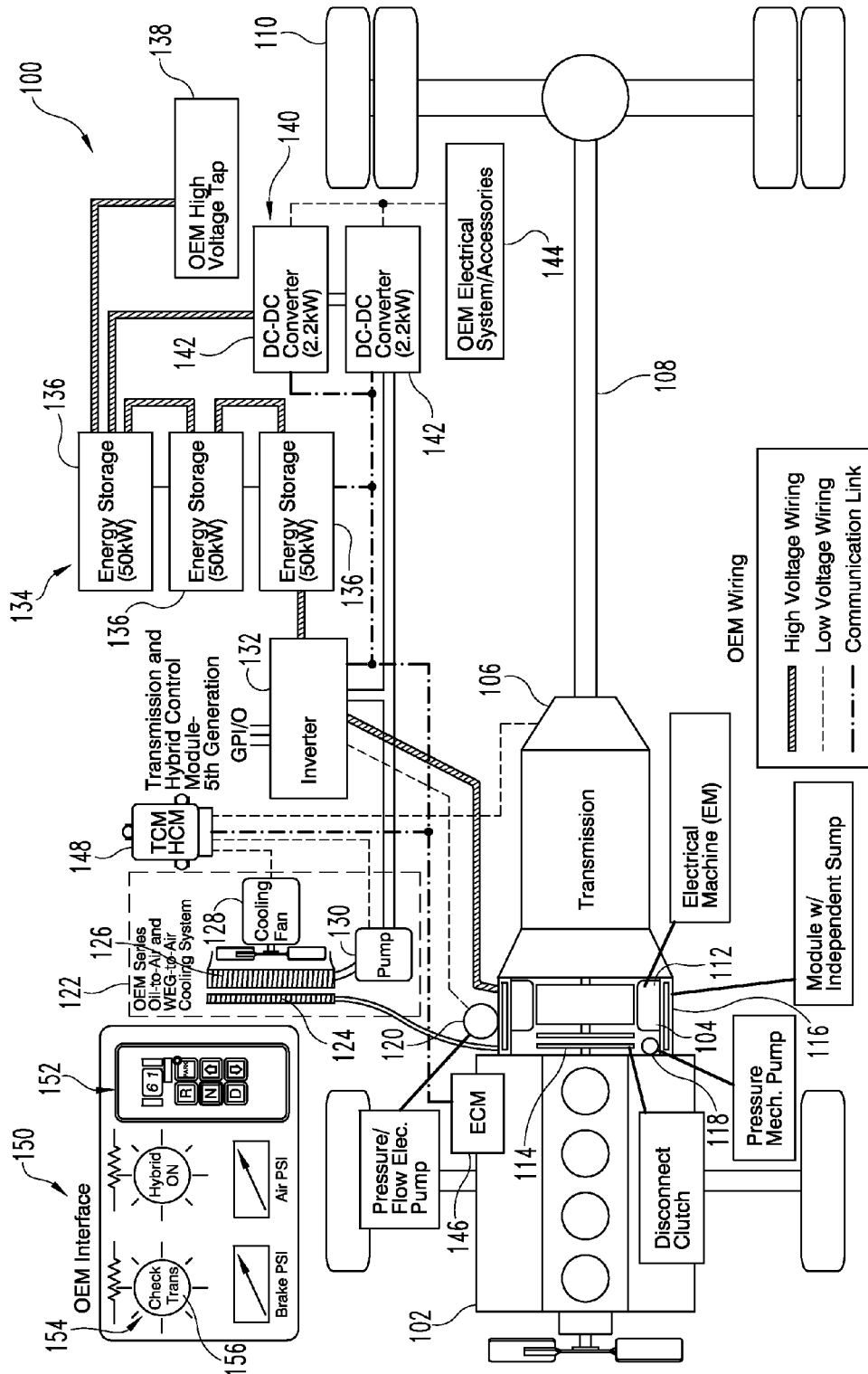


Fig. 1

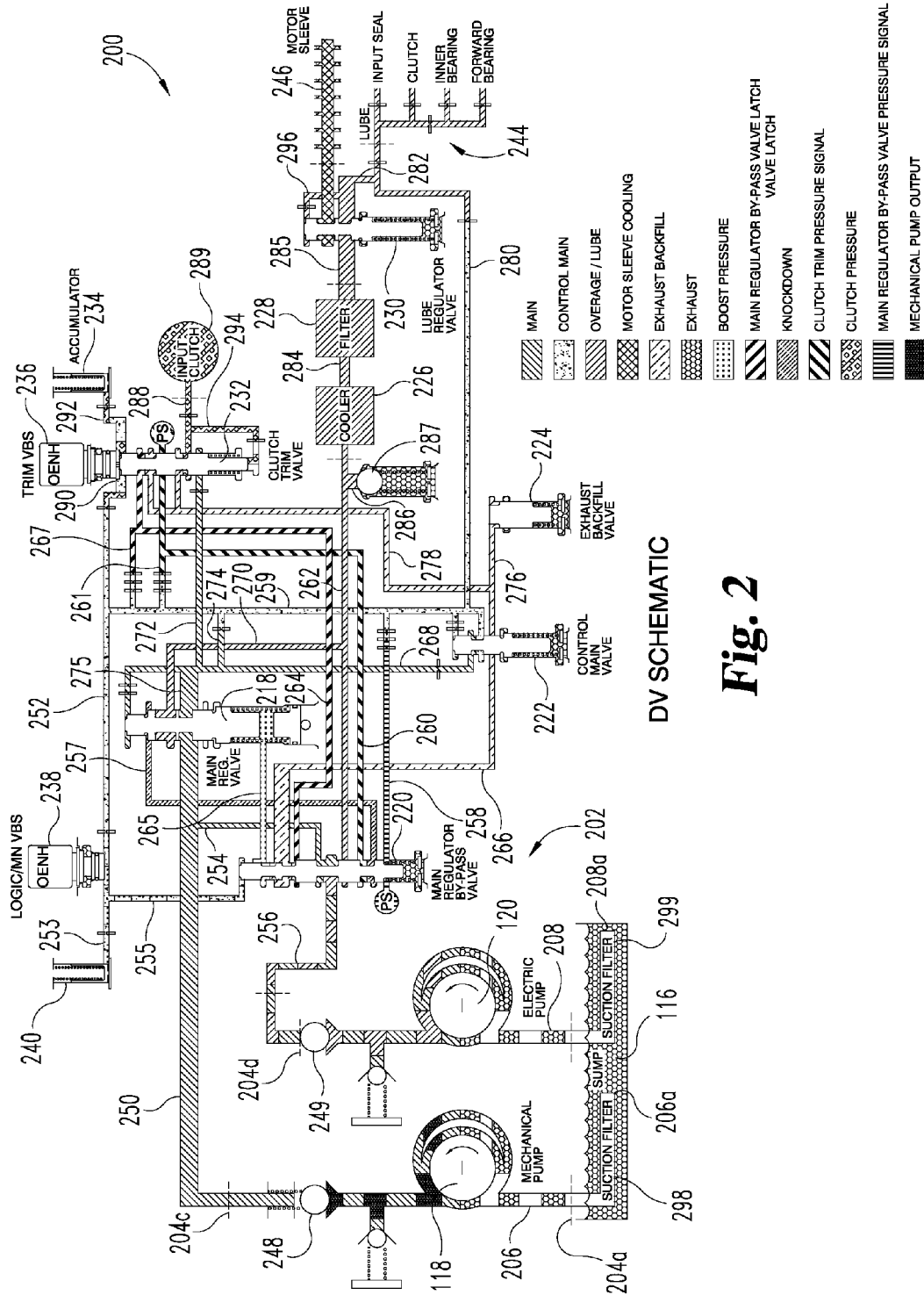
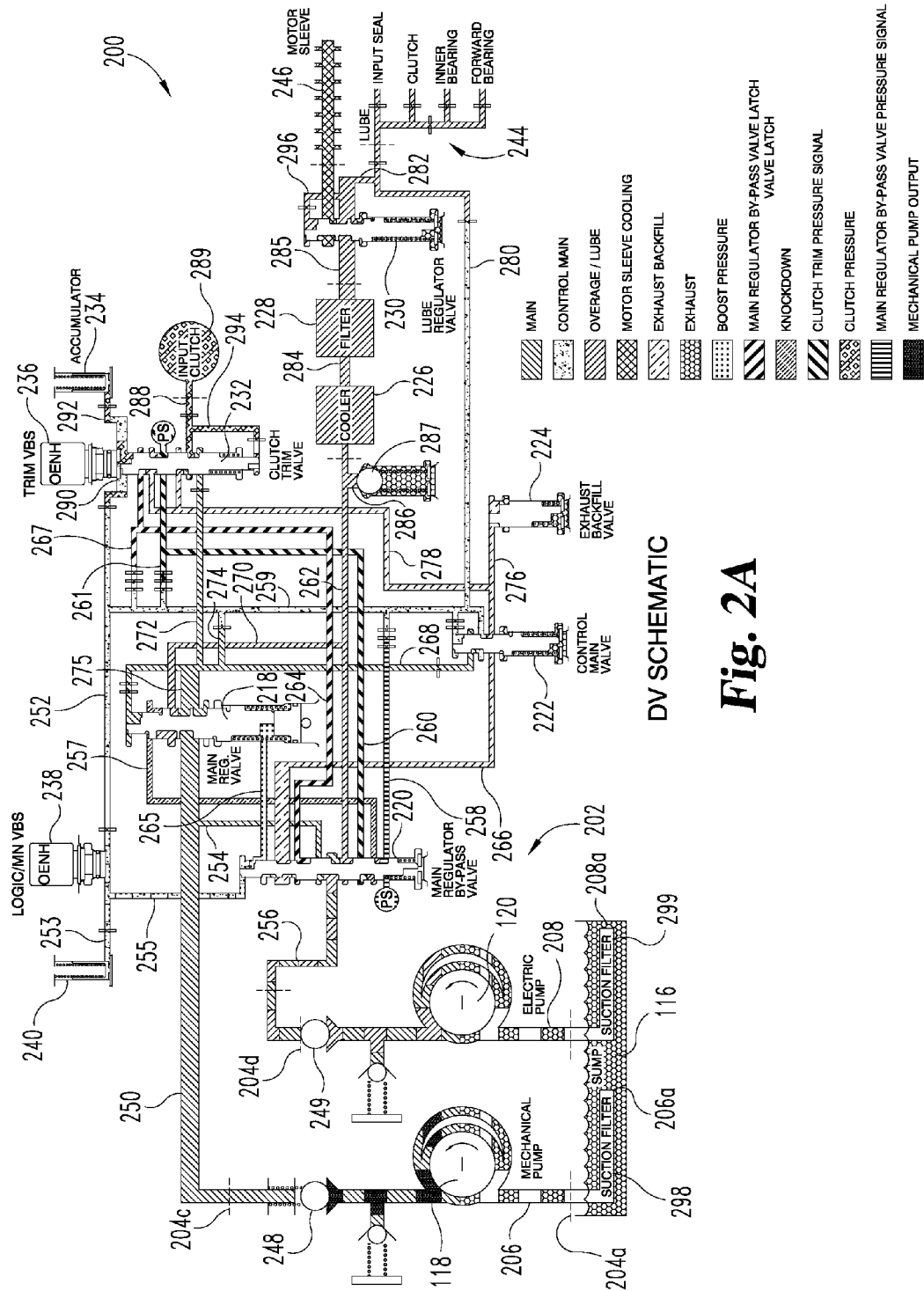


Fig. 2



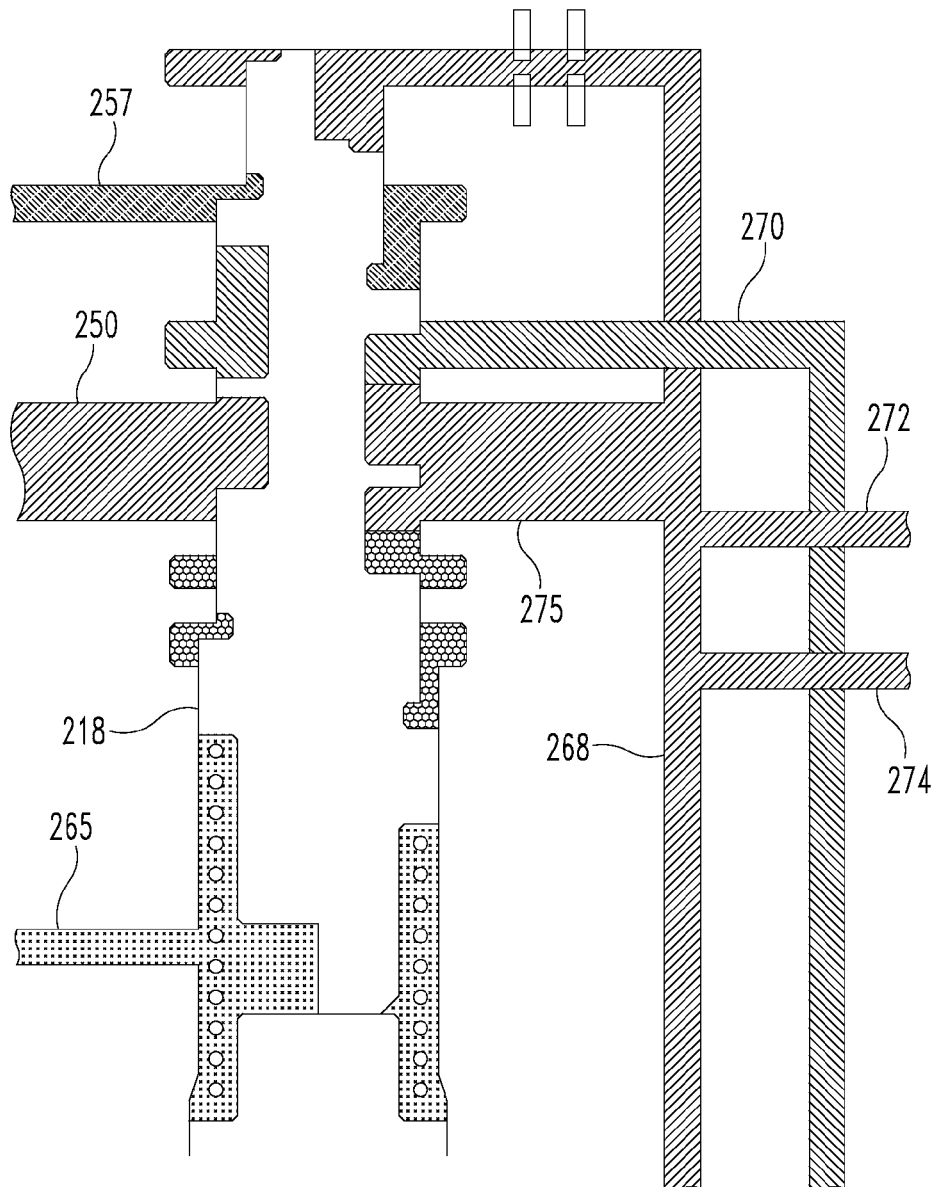
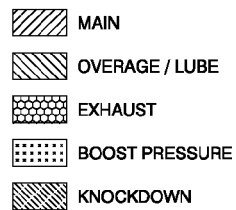


Fig. 3



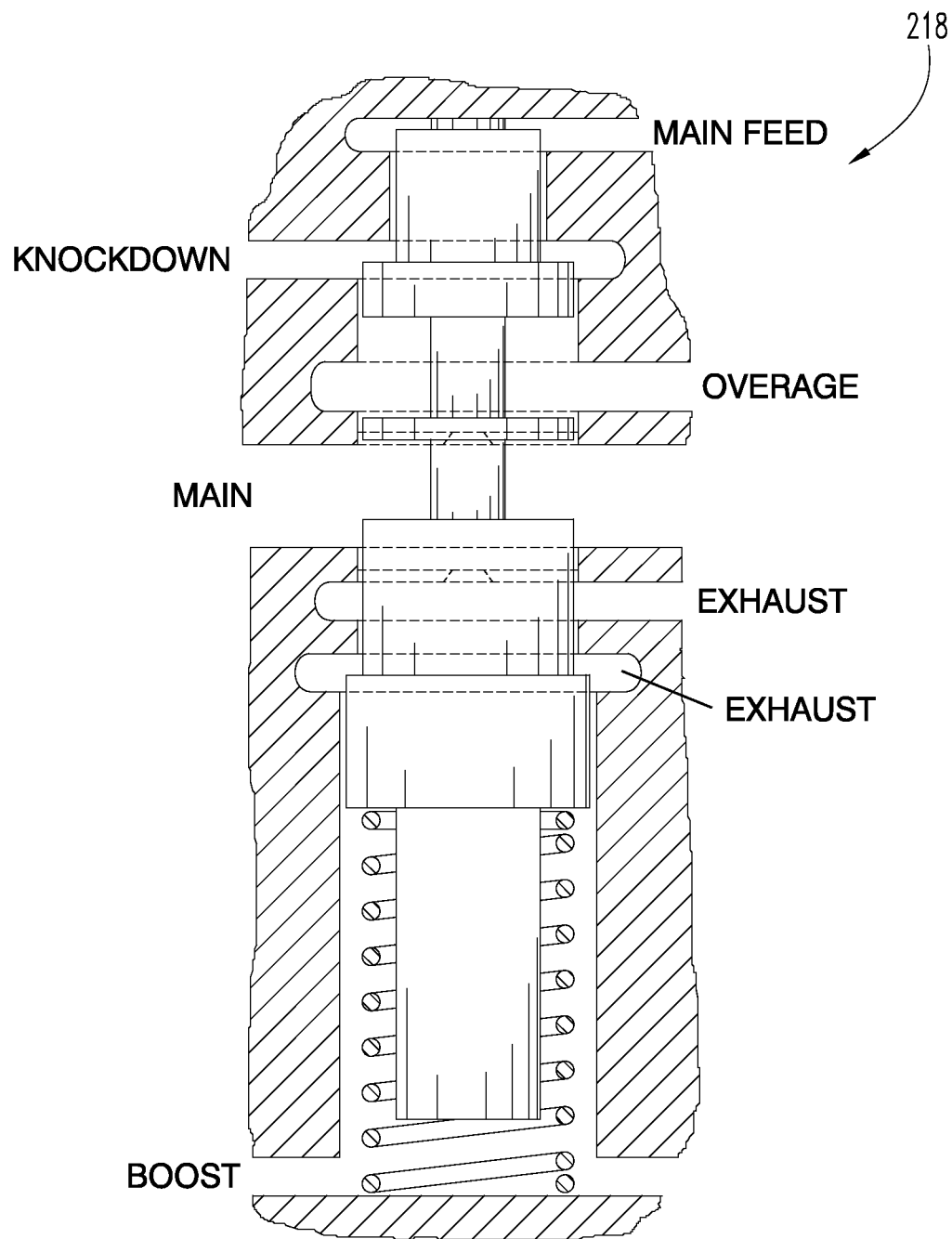
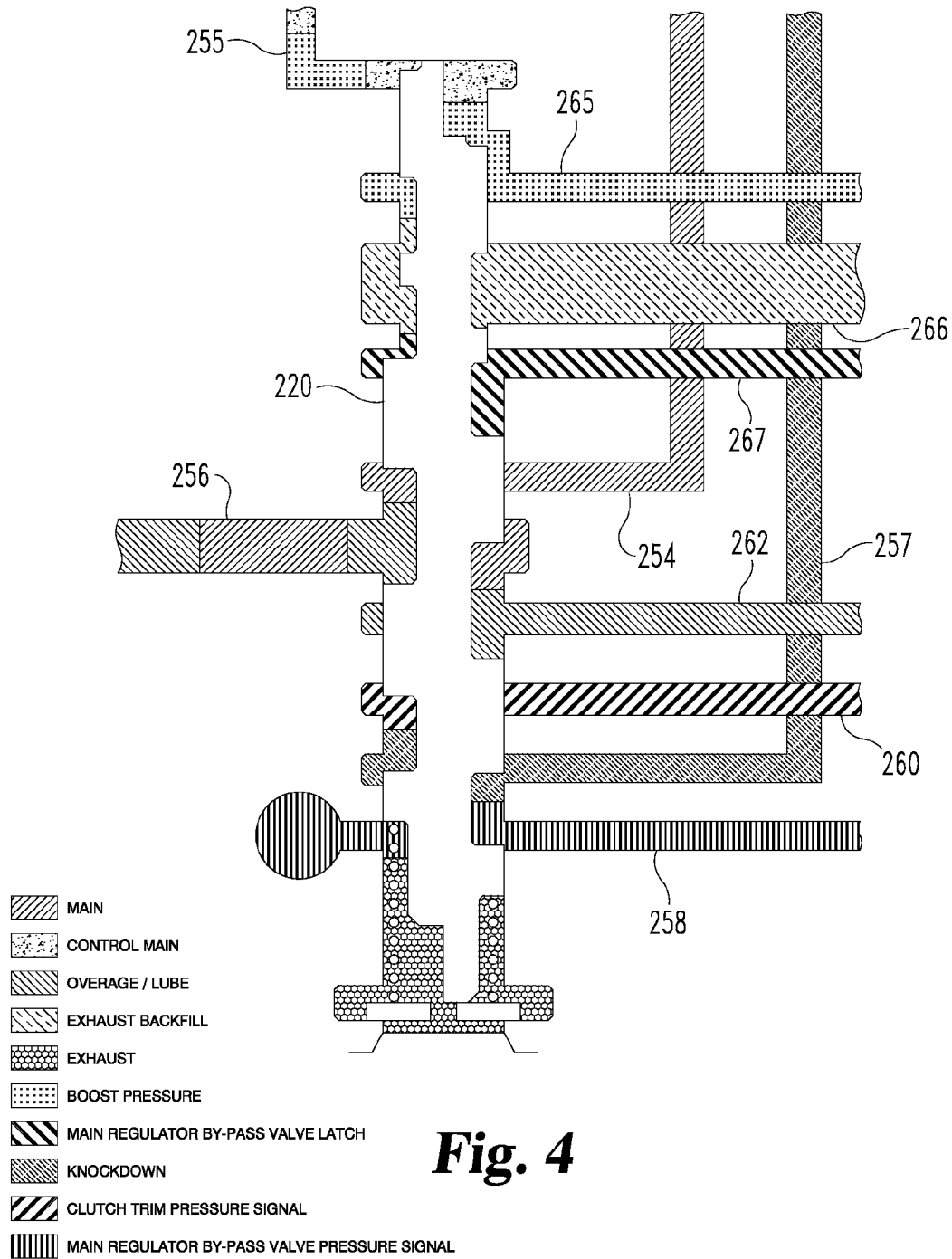


Fig. 3A

**Fig. 4**

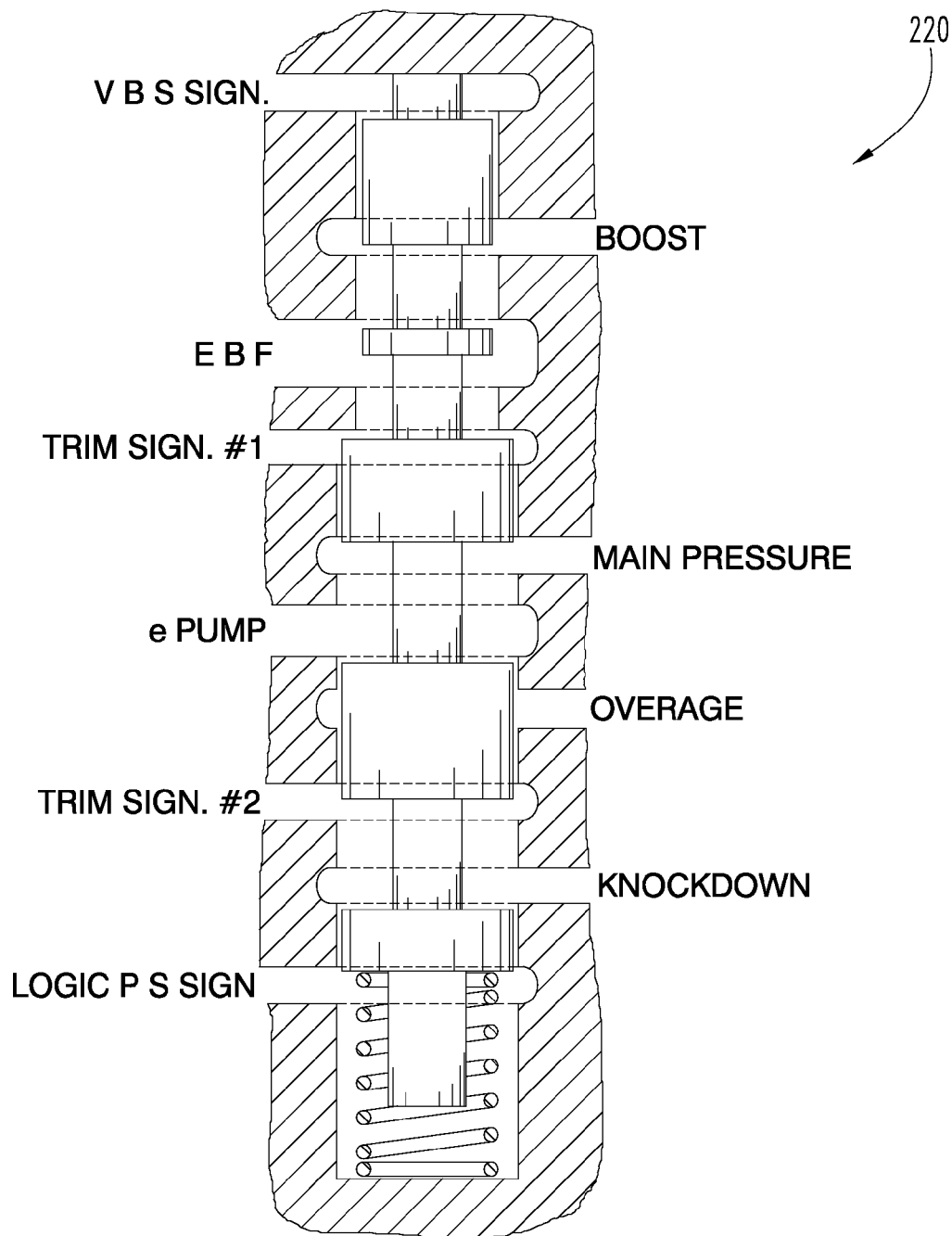


Fig. 4A

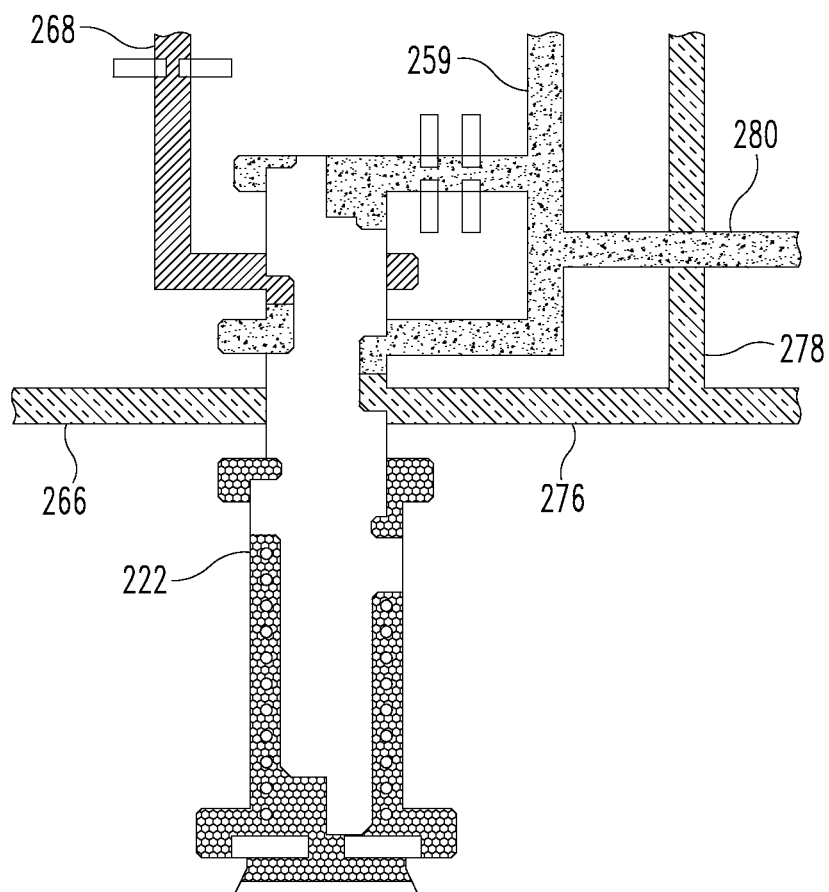
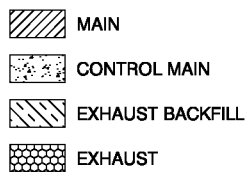


Fig. 5



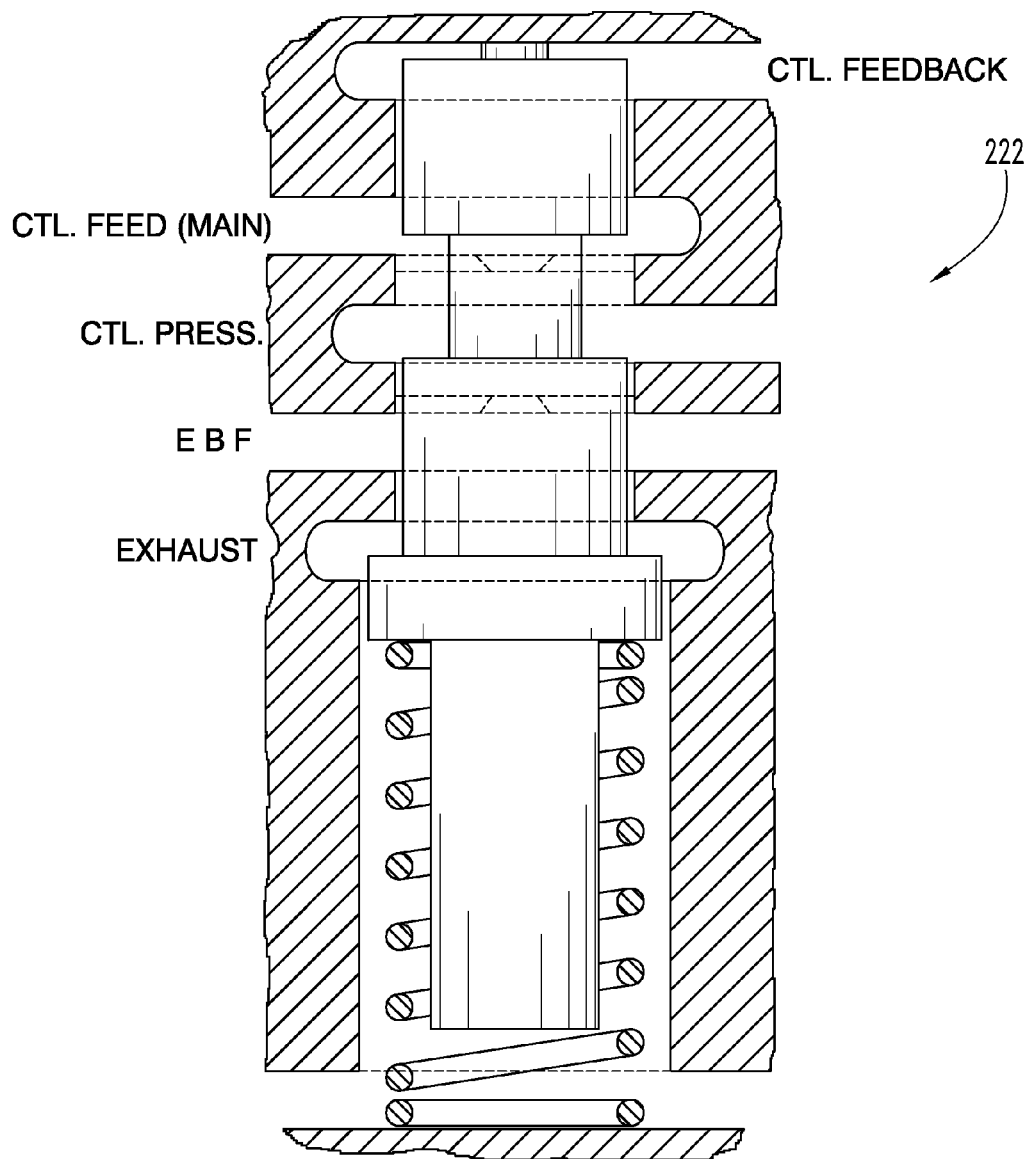


Fig. 5A

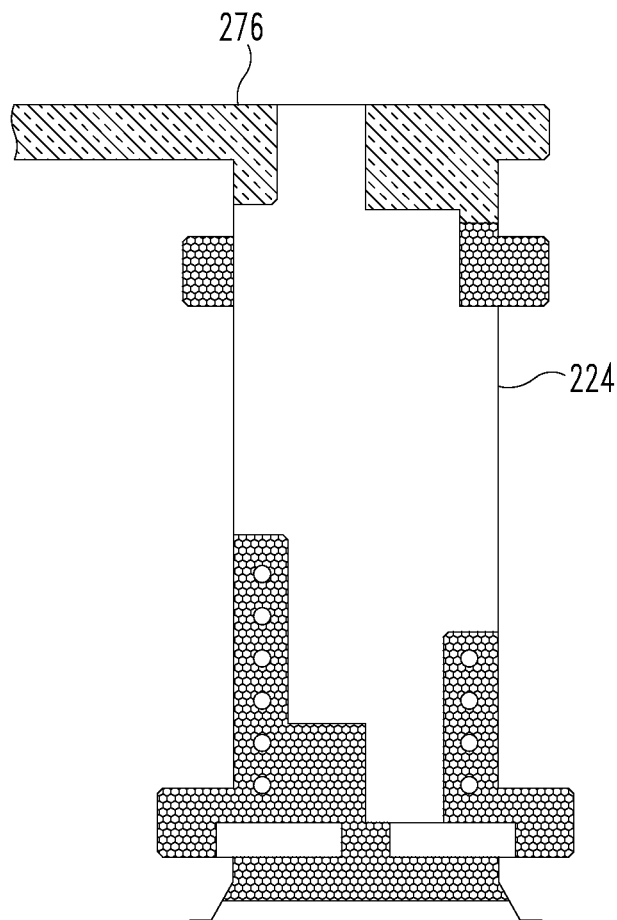
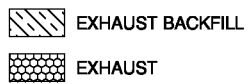


Fig. 6



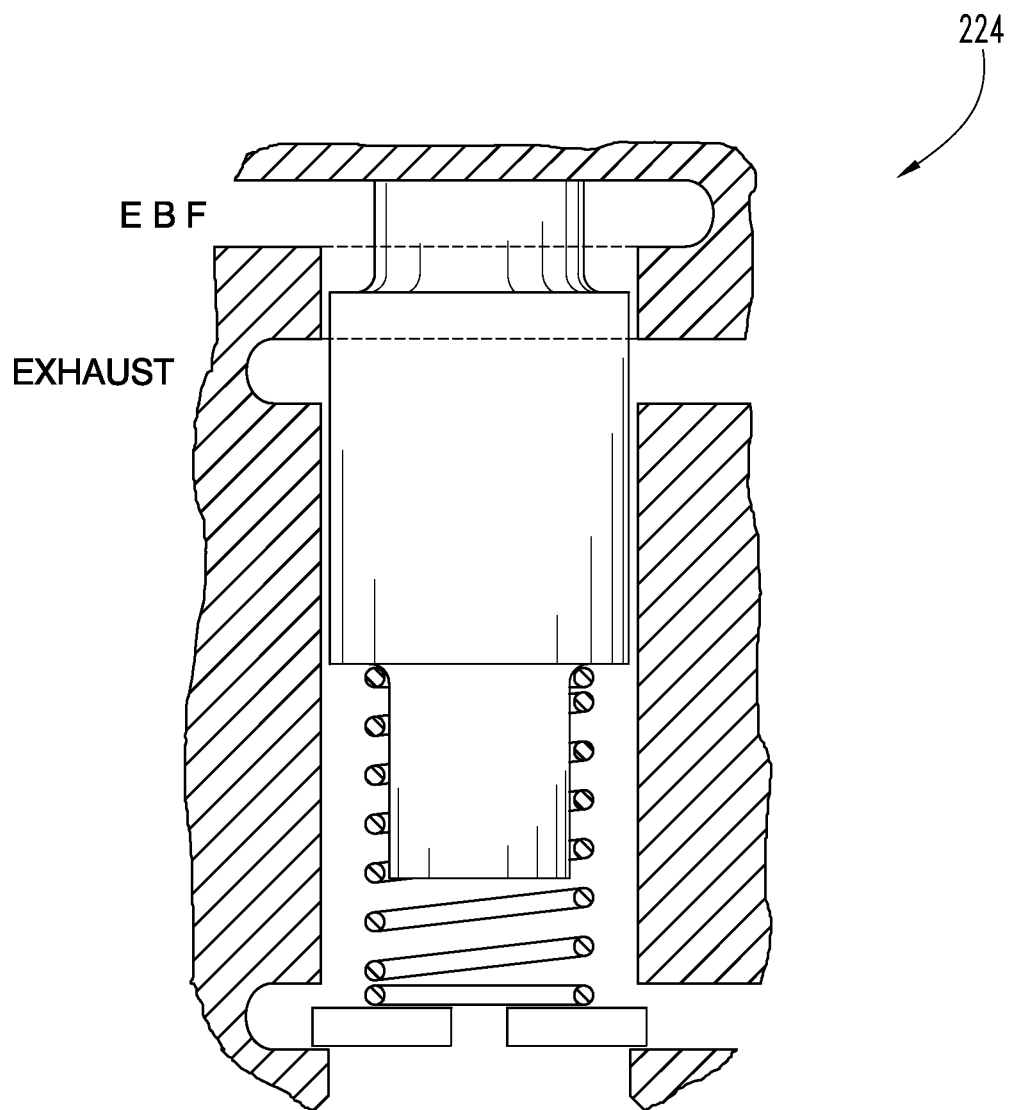


Fig. 6A

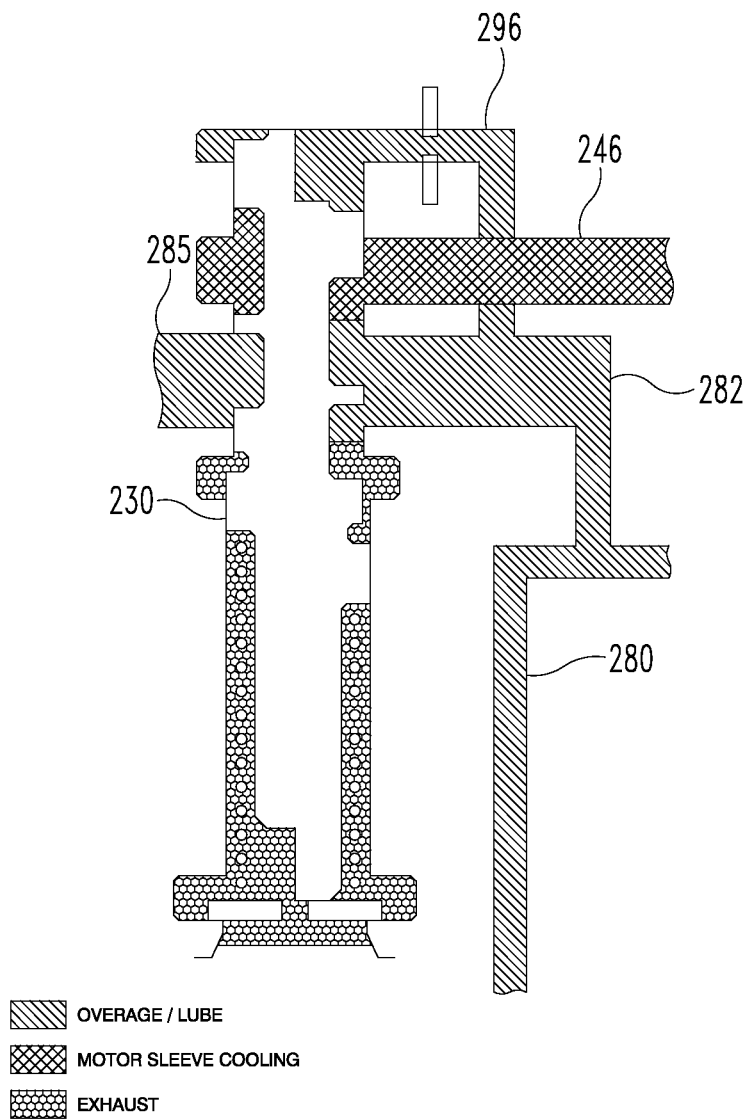


Fig. 7

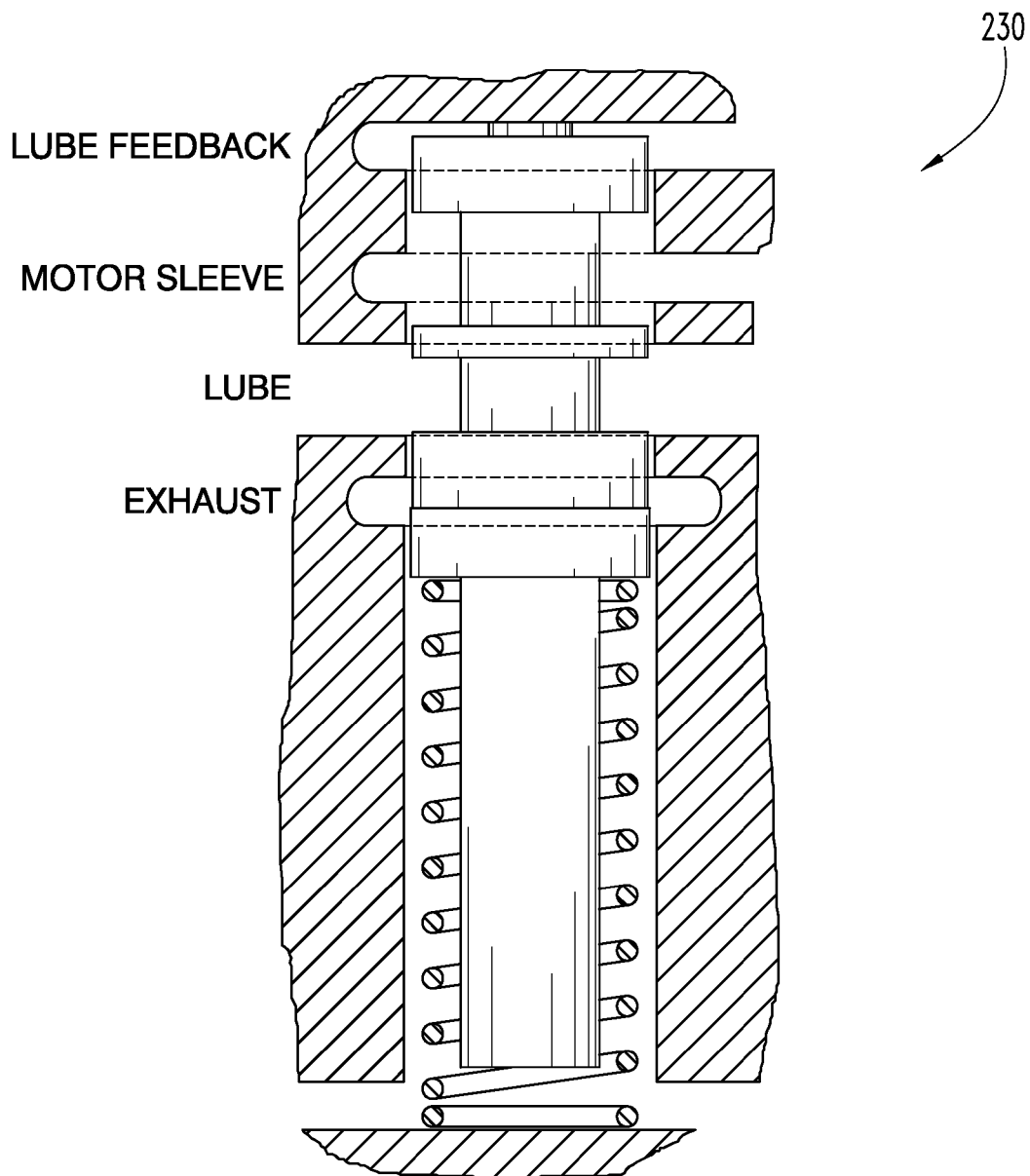


Fig. 7A

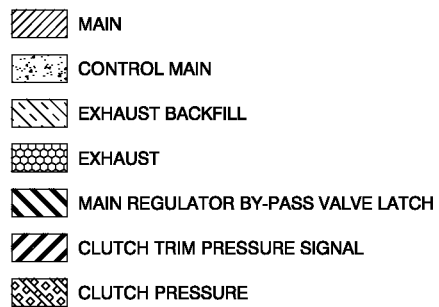
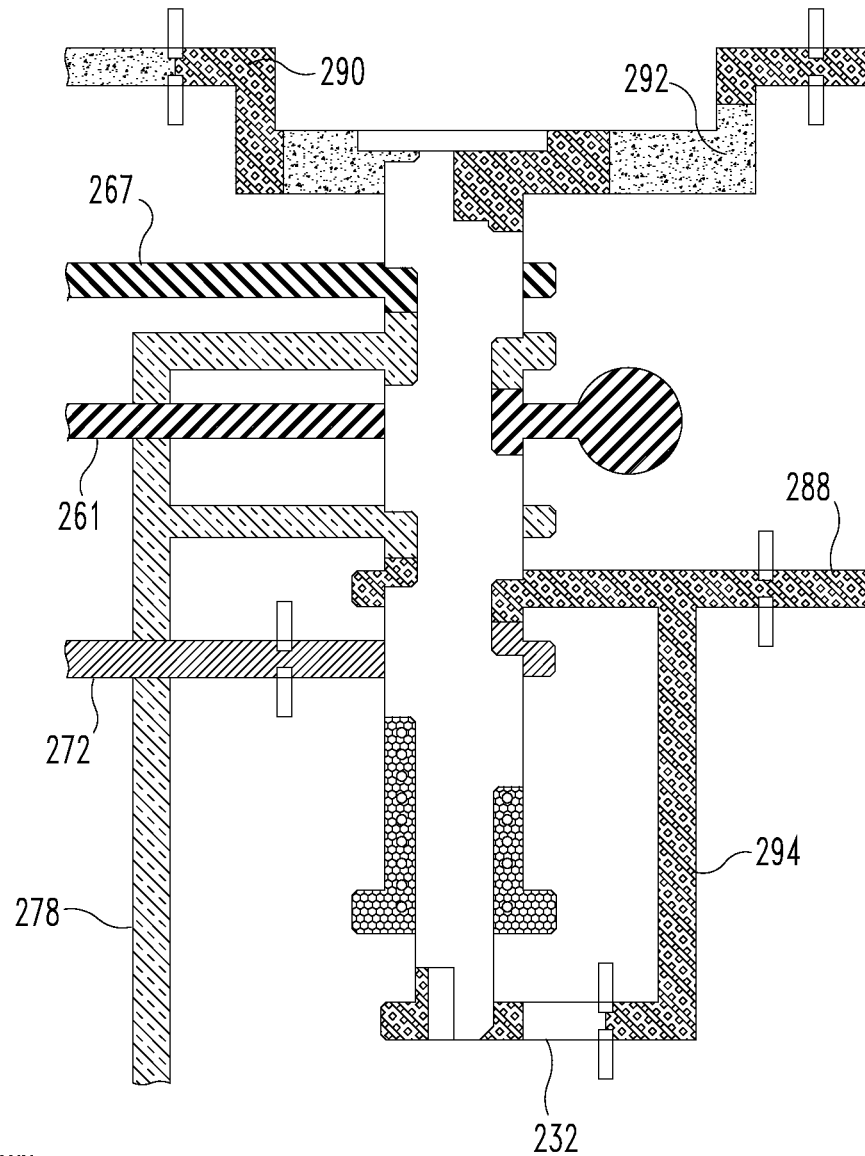


Fig. 8

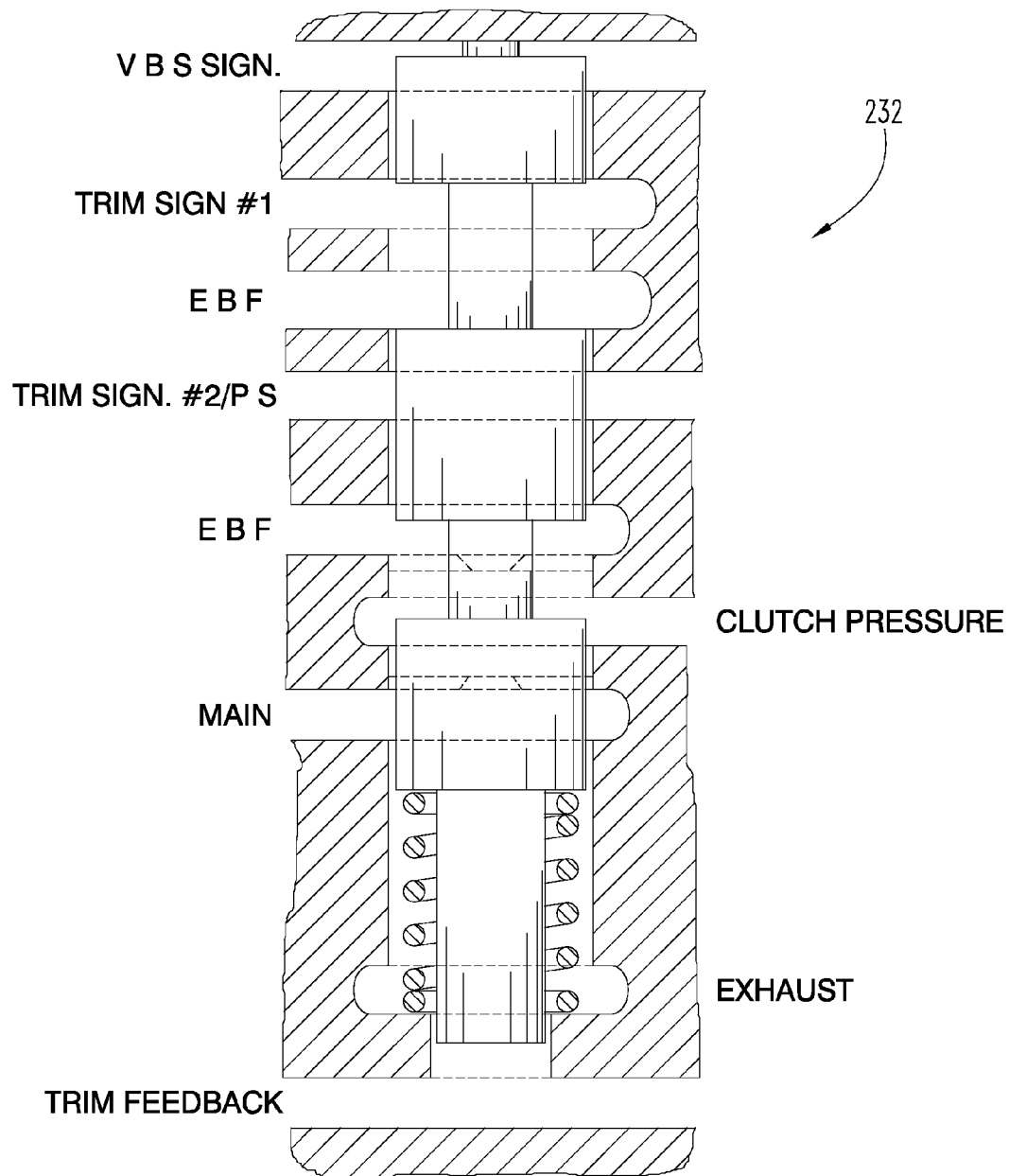


Fig. 8A

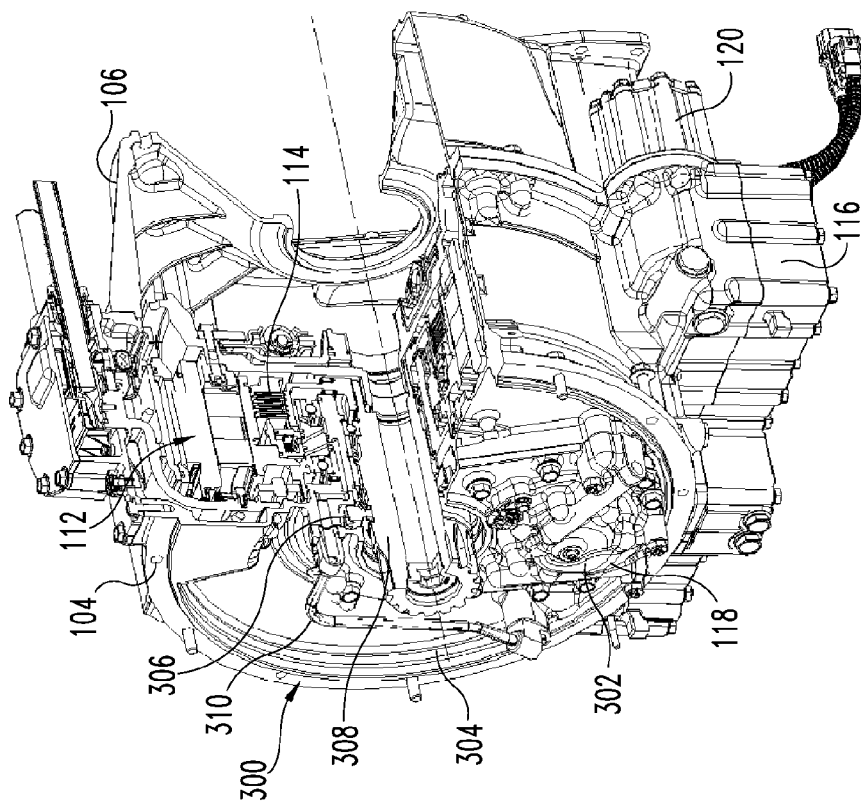


Fig. 9

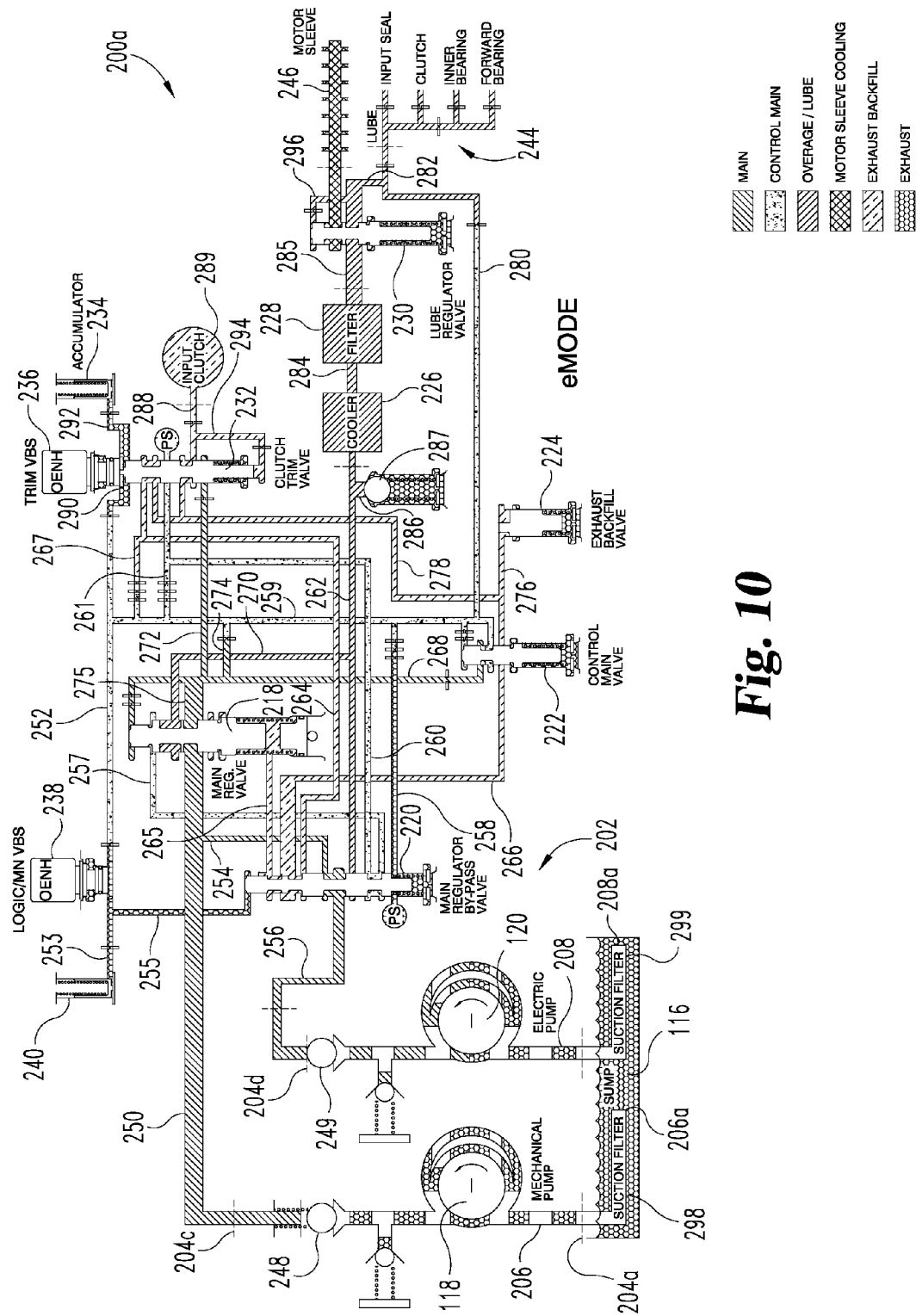


Fig. 10

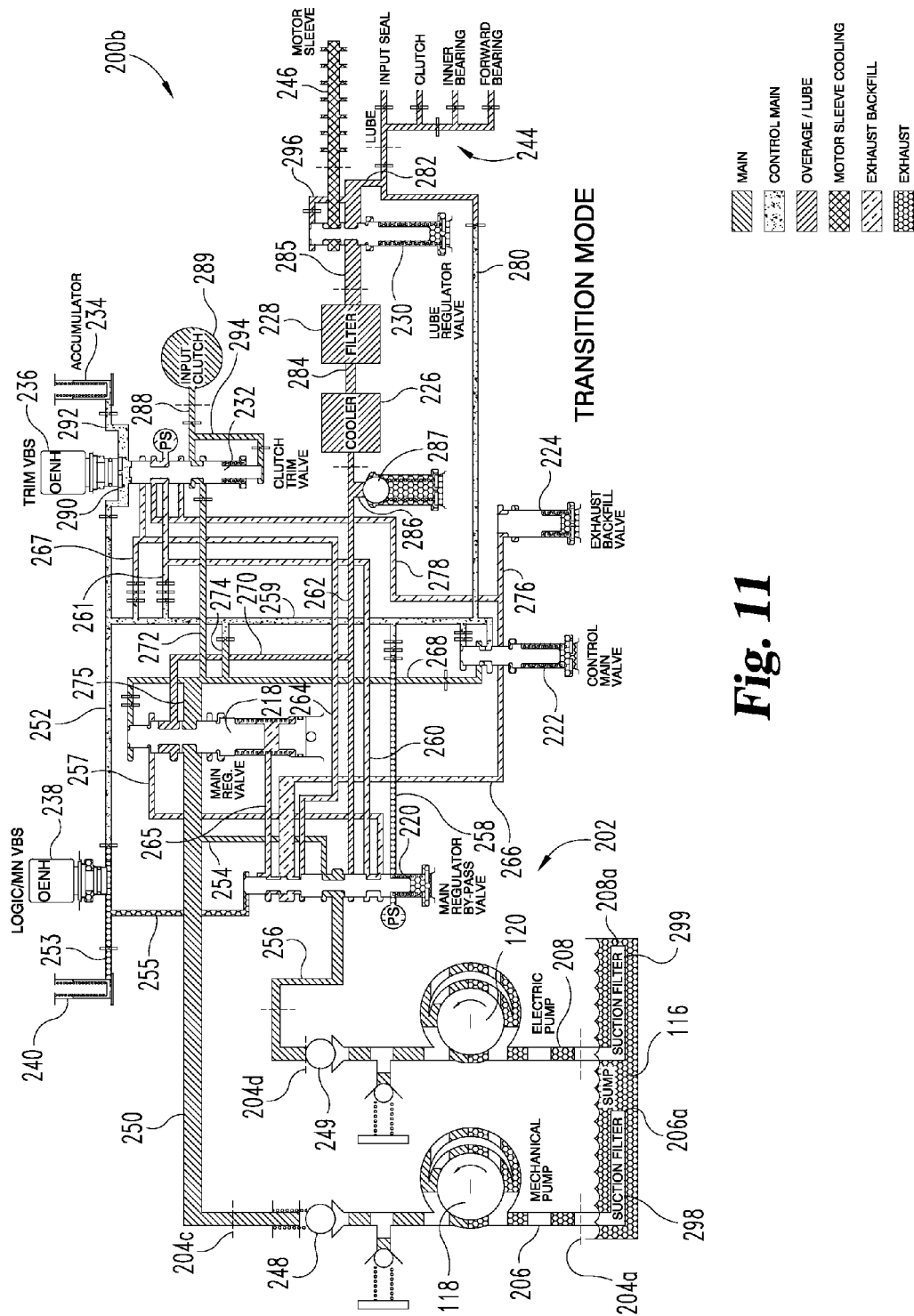


Fig. 11

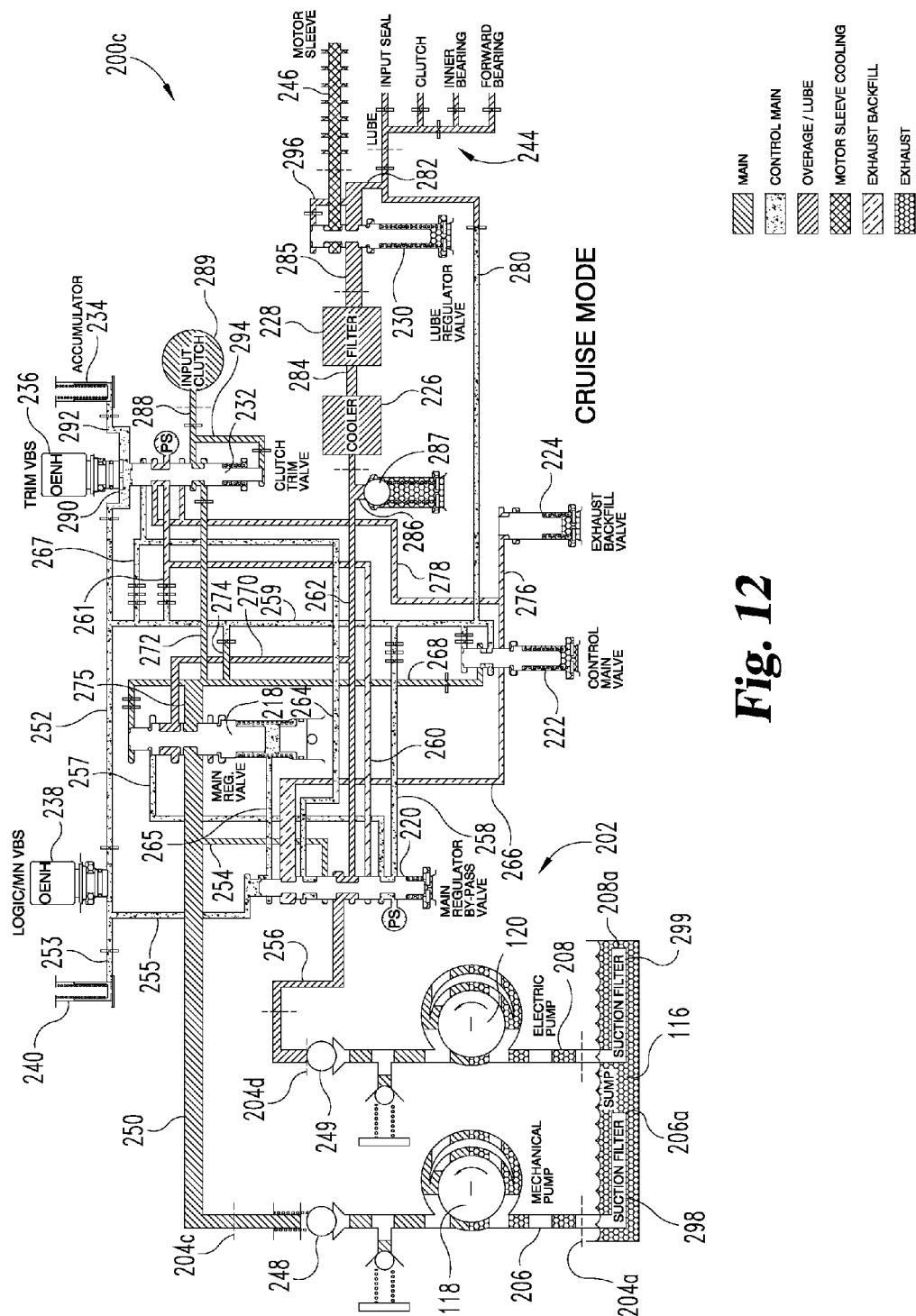
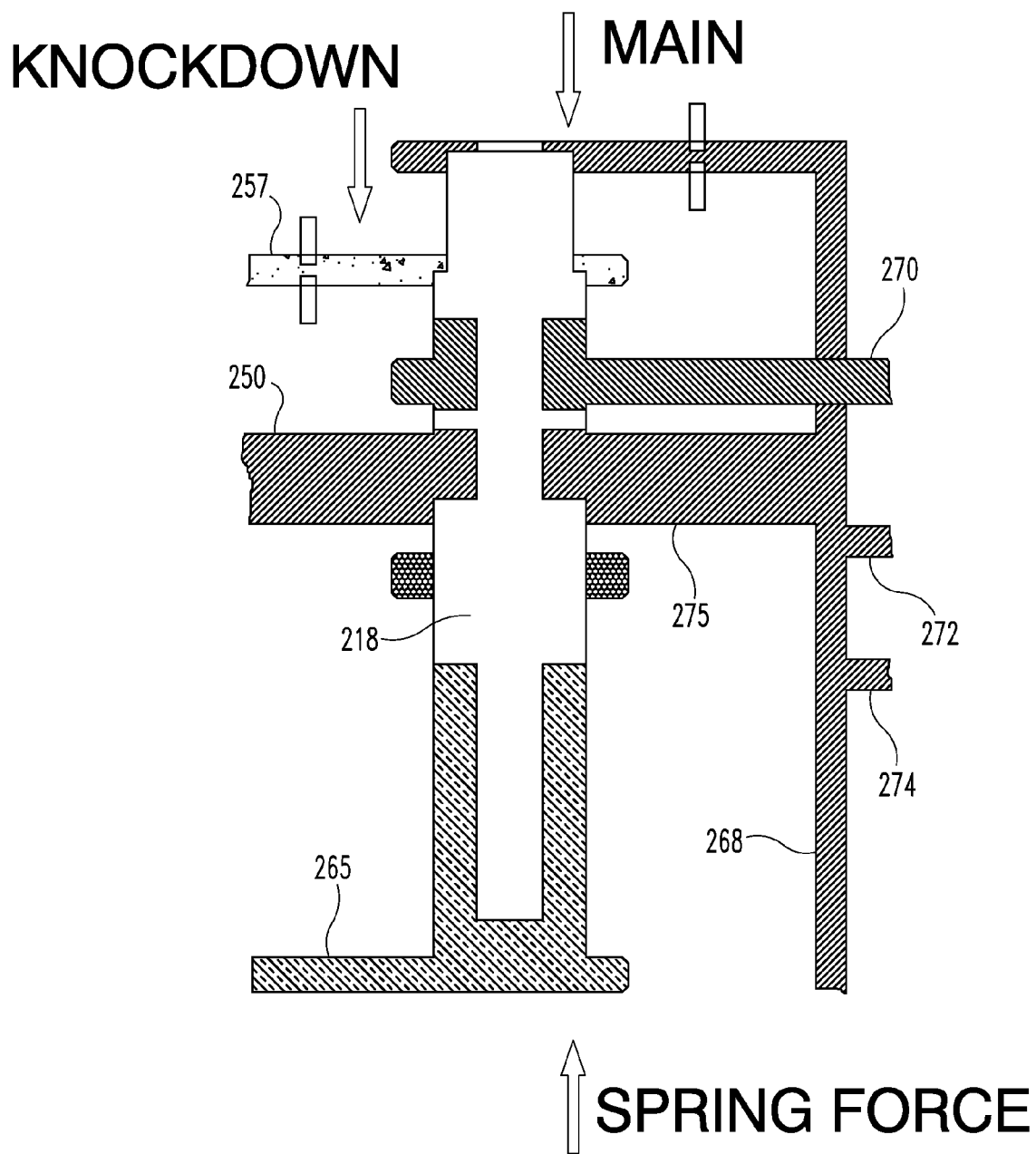
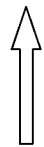
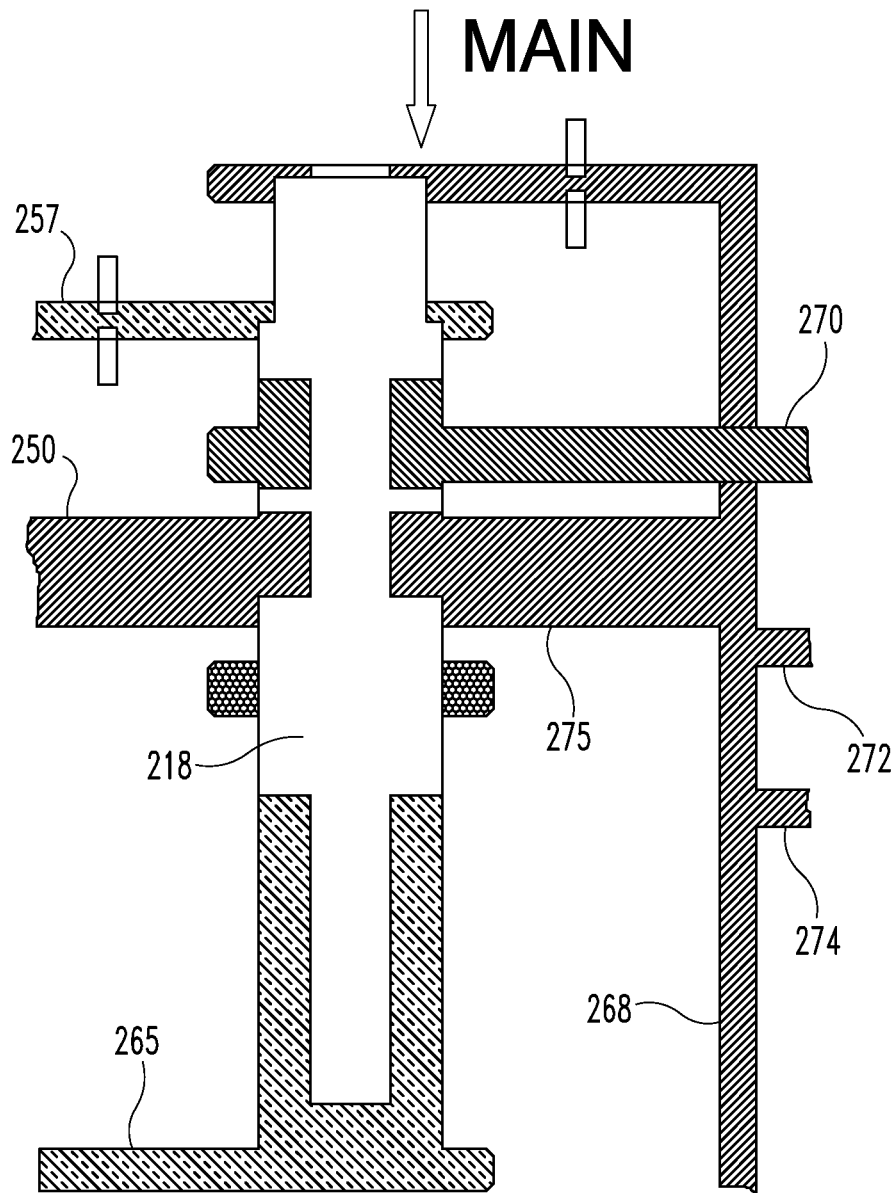


Fig. 12



Reg Pts. = 45psi
eMODE

Fig. 13

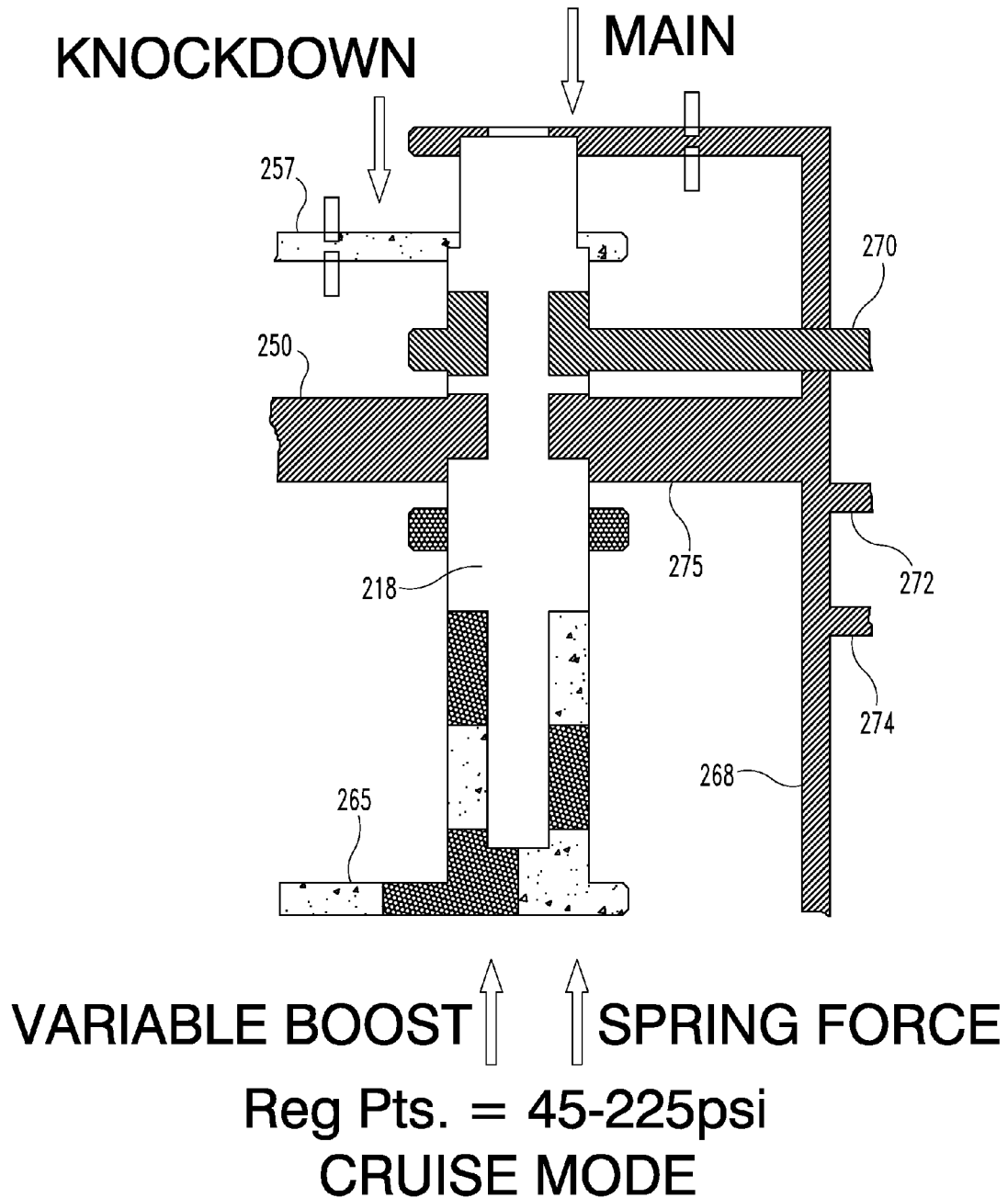


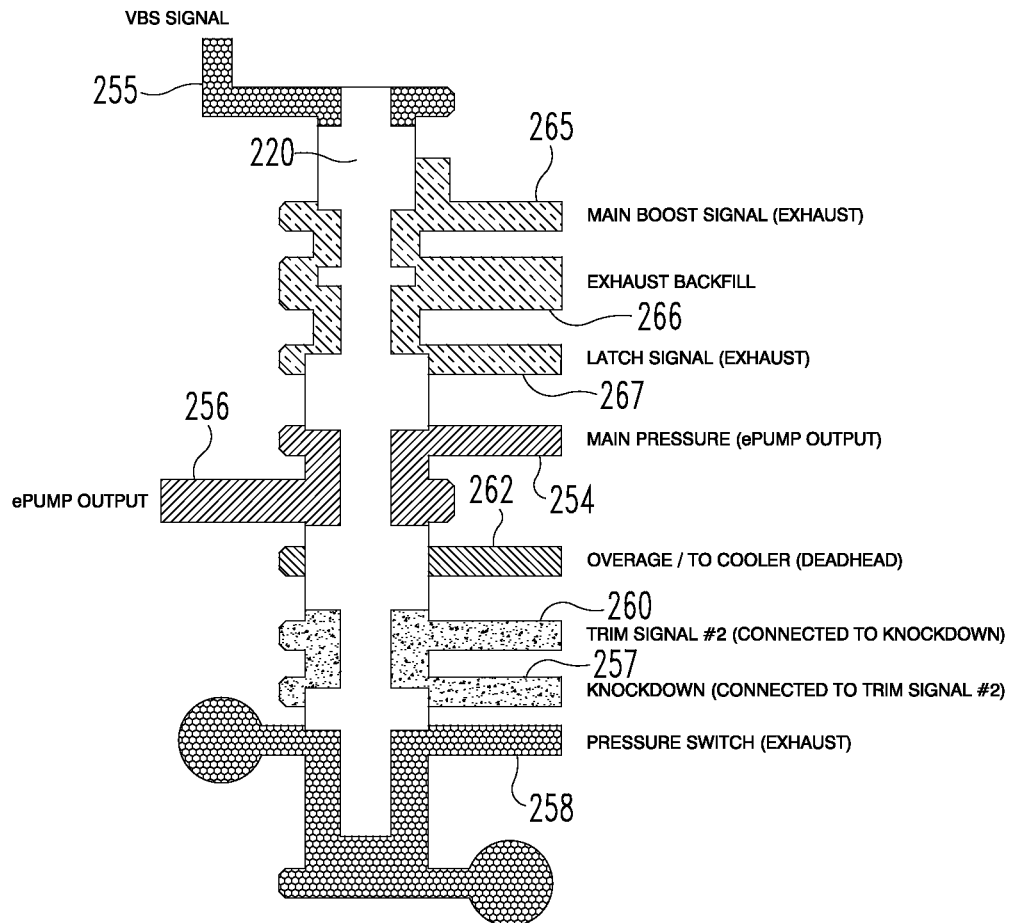
SPRING FORCE

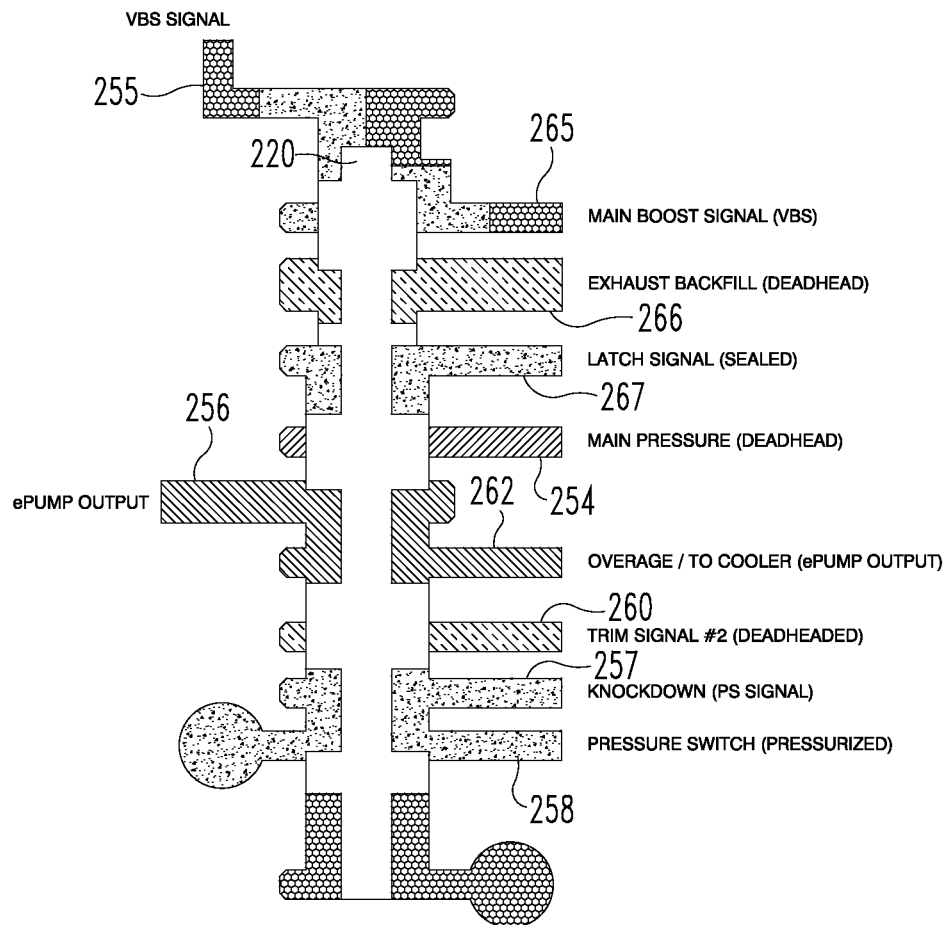
Reg Pts. = 90psi

TRANSITION MODE

Fig. 14

**Fig. 15**

**Fig. 16**

**Fig. 17**

1

MODULATION CONTROL SYSTEM AND METHOD FOR A HYBRID TRANSMISSION

CROSS REFERENCE TO RELATED APPLICATION

This application is a continuation of International Application No. PCT/US2012/025457, filed Feb. 16, 2012 which claims the benefit of U.S. Patent Application Ser. No. 61/443,750 filed Feb. 17, 2011, both of which are hereby incorporated by reference.

BACKGROUND OF THE INVENTION

With the growing concern over global climate change as well as oil supplies, there has been a recent trend to develop various hybrid systems for motor vehicles. While numerous hybrid systems have been proposed, each system typically requires significant modifications to the drive train of the corresponding vehicle. These modifications make it difficult to retrofit the systems to existing vehicles. Moreover, some of these systems have a tendency to cause significant power loss, which in turn hurts the fuel economy for the vehicle. Thus, there is a need for improvement in this field.

One of the areas for improvement of hybrid transmissions is in the construction and arrangement of the hydraulic system. Hybrid vehicles, and in particular the hybrid transmission module associated with such a vehicle, have various lubrication and cooling needs which depend on engine conditions and operational modes. In order to address these needs, oil is delivered by at least one hydraulic pump. The operation of each hydraulic pump is controlled, based in part on the lubrication and cooling needs and based in part on the prioritizing when two hydraulic pumps are included as part of the hydraulic system of the hybrid vehicle. The prioritizing between hydraulic pumps (mechanical and electrical) is based in part on the needs and based in part on the operational state or mode of the hybrid vehicle.

SUMMARY

The hydraulic system (and method) described herein is part of a hybrid transmission module used within a hybrid system adapted for use in vehicles and suitable for use in transportation systems and into other environments. The cooperating hybrid system is generally a self-contained and self-sufficient system which is able to function without the need to significantly drain resources from other systems in the corresponding vehicle or transportation system. The hybrid module includes an electric machine (eMachine).

This self-sufficient design in turn reduces the amount of modifications needed for other systems, such as the transmission and lubrication systems, because the capacities of the other systems do not need to be increased in order to compensate for the increased workload created by the hybrid system. For instance, the hybrid system incorporates its own lubrication and cooling systems that are able to operate independently of the transmission and the engine. The fluid circulation system which can act as a lubricant, hydraulic fluid, and/or coolant, includes a mechanical pump for circulating a fluid, along with an electric pump that supplements the workload for the mechanical pump when needed. As will be explained in further detail below, this dual mechanical/electric pump system helps to reduce the size and weight of the required mechanical pump, and if desired, also allows the system to run in a complete electric mode in which the electric pump solely circulates the fluid.

2

More specifically, the described hydraulic system (for purposes of the exemplary embodiment) is used in conjunction with a hybrid electric vehicle (HEV). Included as part of the described hydraulic system is a parallel arrangement of a mechanical oil pump and an electric oil pump. The control of each pump and the sequence of operation of each pump depends in part on the operational state or the mode of the hybrid vehicle. Various system modes are described herein relating to the hybrid vehicle. As for the hydraulic system disclosed herein, there are three modes which are specifically described and these three modes include an electric mode (eMode), a transition mode, and a cruise mode.

As will be appreciated from the description which follows, the described hydraulic system (and method) is constructed and arranged for addressing the need for component lubrication and for cooling those portions of the hybrid module which experience an elevated temperature during operation of the vehicle. The specific construction and operational characteristics provide an improved hydraulic system for a hydraulic module.

The compact design of the hybrid module has placed demands and constraints on a number of its subcomponents, such as its hydraulics and the clutch. To provide an axially compact arrangement, the piston for the clutch has a recess in order to receive a piston spring that returns the piston to a normally disengaged position. The recess for the spring in the piston creates an imbalance in the opposing surface areas of the piston. This imbalance is exacerbated by the high centrifugal forces that cause pooling of the fluid, which acts as the hydraulic fluid for the piston. As a result, a nonlinear relationship for piston pressure is formed that makes accurate piston control extremely difficult. To address this issue, the piston has an offset section so that both sides of the piston have the same area and diameter. With the areas being the same, the operation of the clutch can be tightly and reliably controlled. The hydraulics for the clutch also incorporate a spill over feature that reduces the risk of hydrostatic lock, while at the same time ensures proper filling and lubrication.

In addition to acting as the hydraulic fluid for the clutch, the hydraulic fluid also acts as a coolant for the eMachine as well as other components. The hybrid module includes a sleeve that defines a fluid channel that encircles the eMachine for cooling purposes. The sleeve has a number of spray channels that spray the fluid from the fluid channel onto the windings of the stator, thereby cooling the windings, which tend to generally generate the majority of the heat for the eMachine. The fluid has a tendency to leak from the hybrid module and around the torque converter. To prevent power loss of the torque converter, the area around the torque converter should be relatively dry, that is, free from the fluid. To keep the fluid from escaping and invading the torque converter, the hybrid module includes a slinger arrangement. Specifically, the hybrid module has a impeller blade that propels the fluid back into the eMachine through a window. Subsequently, the fluid is then drained into the sump so that it can be scavenged and recirculated.

The hybrid module has a number of different operational modes. During the start mode, the battery supplies power to the eMachine as well as to the electric pump. Once the pump achieves the desired oil pressure, the clutch piston is stroked to apply the clutch. With the clutch engaged, the eMachine applies power to start the engine. During the electro-propulsion only mode the clutch is disengaged, and only the eMachine is used to power the torque converter. In the propulsion assist mode, the engine's clutch is engaged, and the eMachine acts as a motor in which both the engine and eMachine drive the torque converter. While in a propulsion-charge mode, the

3

clutch is engaged, and the internal combustion engine solely drives the vehicle. The eMachine is operated in a generator mode to generate electricity that is stored in the energy storage system. The hybrid module can also be used to utilize regenerative braking (i.e., regenerative charging). During regenerative braking, the engine's clutch is disengaged, and the eMachine operates as a generator to supply electricity to the energy storage system. The system is also designed for engine compression braking, in which case the engine's clutch is engaged, and the eMachine operates as a generator as well.

In addition, the system is also designed to utilize both power takeoff (PTO) and electronic PTO (ePTO) modes in order to operate ancillary equipment such as cranes, refrigeration systems, hydraulic lifts, and the like. In a normal PTO mode, the clutch and the PTO system are engaged, and the internal combustion engine is then used to power the ancillary equipment. In an ePTO state, the clutch is disengaged and the eMachine acts as a motor to power the ancillary equipment via the PTO. While in the PTO or ePTO operational modes, the transmission can be in neutral or in gear, depending on the requirements.

Two of the structural considerations important in the design and construction of a hybrid module (transmission) for a hybrid electric vehicle are size and weight. A third factor, reduced cost, usually accompanies reduced size and weight. As the design of the hydraulic system is evaluated, it is important to consider how certain operating techniques, such as multiplexing, might be used to reduce the size, weight and cost associated with the hybrid module. If additional performance benefits can be derived in the process, then there are further advantages to be realized. As disclosed herein. The described hydraulic system for a hybrid module uses existing hydraulic components in a novel manner to provide unique pressure schedules based on torque.

A reduced pressure schedule based on torque should result in reduced spin losses (improves fuel economy) and increased cooler flow (improves reliability). One of the design characteristics related to achieving these results is the multiplexing of solenoids and valves. By not needing to add components, there is no significant increase in size, weight or cost for this technology. Even if selected solenoids and valves have certain design changes for the required flow connections, any increase in size, weight or cost is considered to be minimal.

Further forms, objects, features, aspects, benefits, advantages, and embodiments of the present invention will become apparent from a detailed description and drawings provided herewith.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a diagrammatic illustration of one example of a hybrid system.

FIG. 2 is a diagrammatic illustration of one hydraulic system suitable for use in the FIG. 1 hybrid system.

FIG. 2A is a diagrammatic illustration of the FIG. 2 hydraulic system as a "split-valve" illustration.

FIG. 3 is a diagrammatic, front elevational view, in partial cross-section, of a main regulator valve which comprises one portion of the FIG. 2 hydraulic system.

FIG. 3A is a schematic illustration of the interior construction of the FIG. 3 main regulator valve.

FIG. 4 is a diagrammatic, front elevational view, in partial cross-section, of a main regulator by-pass valve which comprises one portion of the FIG. 2 hydraulic system.

FIG. 4A is a schematic illustration of the interior construction of the FIG. 4 main regulator by-pass valve.

4

FIG. 5 is a diagrammatic, front elevational view, in partial cross-section, of a control main valve which comprises one portion of the FIG. 2 hydraulic system.

FIG. 5A is a schematic illustration of the interior construction of the FIG. 5 control main valve.

FIG. 6 is a diagrammatic, front elevational view, in partial cross-section, of an exhaust backfill valve which comprises one portion of the FIG. 2 hydraulic system.

FIG. 6A is a schematic illustration of the interior construction of the FIG. 6 exhaust backfill valve.

FIG. 7 is a diagrammatic, front elevational view, in partial cross-section, of a lube regulator valve which comprises one portion of the FIG. 2 hydraulic system.

FIG. 7A is a schematic illustration of the interior construction of the FIG. 7 lube regulator valve.

FIG. 8 is a diagrammatic, front elevational view, in partial cross-section, of a clutch trim valve which comprises one portion of the FIG. 2 hydraulic system.

FIG. 8A is a schematic illustration of the interior construction of the FIG. 3 clutch trim valve.

FIG. 9 is a perspective, partial cross-sectional view of a hybrid module-transmission subassembly.

FIG. 10 is a diagrammatic illustration of the FIG. 2 hydraulic system when the hydraulic system is in an eMode.

FIG. 11 is a diagrammatic illustration of the FIG. 2 hydraulic system when the hydraulic system is in a Transition Mode.

FIG. 12 is a diagrammatic illustration of the FIG. 2 hydraulic system when the hydraulic system is in a Cruise Mode.

FIG. 13 is a diagrammatic illustration of the FIG. 3 main regulator valve in the eMode.

FIG. 14 is a diagrammatic illustration of the FIG. 3 main regulator valve in the Transition Mode.

FIG. 15 is a diagrammatic illustration of the FIG. 3 main regulator valve in the Cruise Mode.

FIG. 16 is a diagrammatic illustration of the FIG. 4 main regulator by-pass valve in the eMode.

FIG. 17 is a diagrammatic illustration of the FIG. 4 main regulator by-pass valve in the Cruise Mode.

DETAILED DESCRIPTION

For the purposes of promoting an understanding of the disclosure, reference will now be made to the embodiments illustrated in the drawings and specific language will be used to describe the same. It will nevertheless be understood that no limitation of the scope of the disclosure is thereby intended, such alterations and further modifications in the illustrated device and its use, and such further applications of the principles of the disclosure as illustrated therein being contemplated as would normally occur to one skilled in the art to which the disclosure relates.

FIG. 1 shows a diagrammatic view of a hybrid system 100 according to one embodiment. The hybrid system 100 illustrated in FIG. 1 is adapted for use in commercial-grade trucks as well as other types of vehicles or transportation systems, but it is envisioned that various aspects of the hybrid system 100 can be incorporated into other environments. As shown, the hybrid system 100 includes an engine 102, a hybrid module 104, an automatic transmission 106, and a drive train 108 for transferring power from the transmission 106 to wheels 110. The hybrid module 104 incorporates an electrical machine, commonly referred to as an eMachine 112, and a clutch 114 that operatively connects and disconnects the engine 102 with the eMachine 112 and the transmission 106.

The hybrid module 104 is designed to operate as a self-sufficient unit, that is, it is generally able to operate independently of the engine 102 and transmission 106. In particular,

its hydraulics, cooling and lubrication do not directly rely upon the engine **102** and the transmission **106**. The hybrid module **104** includes a sump **116** that stores and supplies fluids, such as oil, lubricants, or other fluids, to the hybrid module **104** for hydraulics, lubrication, and cooling purposes. While the terms oil or lubricant or lube will be used interchangeably herein, these terms are used in a broader sense to include various types of lubricants, such as natural or synthetic oils, as well as lubricants having different properties. To circulate the fluid, the hybrid module **104** includes a mechanical pump **118** and an electric pump **120** in cooperation with a hydraulic system **200** (see FIG. 2). With this parallel combination of both the mechanical pump **118** and electric pump **120**, the overall size is reduced. The electric pump **120** cooperates with the mechanical pump **118** to provide extra pumping capacity when required. The electric pump **120** is also used for hybrid system needs when there is no drive input to operate the mechanical pump **118**. In addition, it is contemplated that the flow through the electric pump **120** can be used to detect low fluid conditions for the hybrid module **104**.

The hybrid system **100** further includes a cooling system **122** that is used to cool the fluid supplied to the hybrid module **104** as well as the water-ethylene-glycol (WEG) to various other components of the hybrid system **100**. In one variation, the WEG can also be circulated through an outer jacket of the eMachine **112** in order to cool the eMachine **112**. Although the hybrid system **100** has been described with respect to a WEG coolant, other types of antifreezes and cooling fluids, such as water, alcohol solutions, etc., can be used. With continued reference to FIG. 1, the cooling system **122** includes a fluid radiator **124** that cools the fluid for the hybrid module **104**. The cooling system **122** further includes a main radiator **126** that is configured to cool the antifreeze for various other components in the hybrid system **100**. Usually, the main radiator **126** is the engine radiator in most vehicles, but the main radiator **126** does not need to be the engine radiator. A cooling fan **128** flows air through both fluid radiator **124** and main radiator **126**. A circulating or coolant pump **130** circulates the antifreeze to the main radiator **126**. It should be recognized that other various components besides the ones illustrated can be cooled using the cooling system **122**. For instance, the transmission **106** and/or the engine **102** can be cooled as well via the cooling system **122**.

The eMachine **112** in the hybrid module **104**, depending on the operational mode, at times acts as a generator and at other times as a motor. When acting as a motor, the eMachine **112** draws alternating current (AC). When acting as a generator, the eMachine **112** creates AC. An inverter **132** converts the AC from the eMachine **112** and supplies it to an energy storage system **134**. In the illustrated example, the energy storage system **134** stores the energy and resupplies it as direct current (DC). When the eMachine **112** in the hybrid module **104** acts as a motor, the inverter **132** converts the DC power to AC, which in turn is supplied to the eMachine **112**. The energy storage system **134** in the illustrated example includes three energy storage modules **136** that are daisy-chained together to supply high voltage power to the inverter **132**. The energy storage modules **136** are, in essence, electrochemical batteries for storing the energy generated by the eMachine **112** and rapidly supplying the energy back to the eMachine **112**. The energy storage modules **136**, the inverter **132**, and the eMachine **112** are operatively coupled together through high voltage wiring as is depicted by the line illustrated in FIG. 1. While the illustrated example shows the energy storage system **134** including three energy storage modules **136**, it should be recognized that the energy storage system **134** can include more or less energy storage modules

136 than is shown. Moreover, it is envisioned that the energy storage system **134** can include any system for storing potential energy, such as through chemical means, pneumatic accumulators, hydraulic accumulators, springs, thermal storage systems, flywheels, gravitational devices, and capacitors, to name just a few examples.

High voltage wiring connects the energy storage system **134** to a high voltage tap **138**. The high voltage tap **138** supplies high voltage to various components attached to the vehicle. A DC-DC converter system **140**, which includes one or more DC-DC converter modules **142**, converts the high voltage power supplied by the energy storage system **134** to a lower voltage, which in turn is supplied to various systems and accessories **144** that require lower voltages. As illustrated in FIG. 1, low voltage wiring connects the DC-DC converter modules **142** to the low voltage systems and accessories **144**.

The hybrid system **100** incorporates a number of control systems for controlling the operations of the various components. For example, the engine **102** has an engine control module (ECM) **146** that controls various operational characteristics of the engine **102** such as fuel injection and the like. A transmission/hybrid control module (TCM/HCM) **148** substitutes for a traditional transmission control module and is designed to control both the operation of the transmission **106** as well as the hybrid module **104**. The transmission/hybrid control module **148** and the engine control module **146** along with the inverter **132**, energy storage system **134**, and DC-DC converter system **140** communicate along a communication link as is depicted in FIG. 1.

To control and monitor the operation of the hybrid system **100**, the hybrid system **100** includes an interface **150**. The interface **150** includes a shift selector **152** for selecting whether the vehicle is in drive, neutral, reverse, etc., and an instrument panel **154** that includes various indicators **156** of the operational status of the hybrid system **100**, such as check transmission, brake pressure, and air pressure indicators, to name just a few.

As noted before, the hybrid system **100** is configured to be readily retrofitted to existing vehicle designs with minimal impact to the overall design. All of the systems including, but not limited to, mechanical, electrical, cooling, controls, and hydraulic systems, of the hybrid system **100** have been configured to be a generally self-contained unit such that the remaining components of the vehicle do not need significant modifications. The more components that need to be modified, the more vehicle design effort and testing is required, which in turn reduces the chance of vehicle manufacturers adopting newer hybrid designs over less efficient, preexisting vehicle designs. In other words, significant modifications to the layout of a preexisting vehicle design for a hybrid retrofit require, then, vehicle and product line modifications and expensive testing to ensure the proper operation and safety of the vehicle, and this expense tends to lessen or slow the adoption of hybrid systems. As will be recognized, the hybrid system **100** not only incorporates a mechanical architecture that minimally impacts the mechanical systems of pre-existing vehicle designs, but the hybrid system **100** also incorporates a control/electrical architecture that minimally impacts the control and electrical systems of pre-existing vehicle designs.

Referring to FIGS. 2 and 2A, there is illustrated in diagrammatic form a hydraulic system **200** which is suitably constructed and arranged for use with hybrid system **100**. More particularly, hydraulic system **200** is a portion of hybrid module **104**. Since the FIGS. 2 and 2A illustrations include components which interface with a sump module assembly **202**, broken lines **204** are used in FIGS. 2 and 2A to denote, in

diagrammatic form, the functional locations of the oil connections from other hydraulic components to the sump module assembly **202**. Lower case letters are used in conjunction with reference numeral **204** in order to distinguish the various broken line locations (**204a**, **204b**, etc.). For example, the sump **116** is part of the sump module assembly **202**, while mechanical pump **118** and electric pump **120** may not technically be considered actual component parts of the sump module assembly **202**, though this convention is somewhat arbitrary. The mechanical pump **118** and the electric pump **120** each have an oil connection with the sump module assembly **202**. Sump **116** is independent of the sump for the automatic transmission **106**. Broken line **204a** diagrammatically illustrates the location of flow communication between the mechanical pump inlet conduit **206** and sump **116**. Similarly, broken line **204b** denotes the location of flow communication between the electric pump inlet conduit **208** and sump **116**. Inlet conduit **206** defines inlet conduit opening **206a**. Inlet conduit **208** defines inlet conduit opening **208a**.

The FIG. **2** illustration shows the standard schematic for the hydraulic system **200** with all the valves in the OFF/installed position. The FIG. **2A** illustration shows the valves in a "split" configuration with the left side depicting the OFF/installed position. The right side depicts the ON/applied position for each valve. The FIG. **2A** illustration is used for the detailed valve illustrations of FIGS. **3-8**. The same hydraulic system reference number (**200**) is used for both illustrations as the structures are the same.

With continued reference to FIGS. **2** and **2A**, on the flow exiting sides of the two oil pumps, broken line **204c** denotes the location where the outlet **210** of mechanical pump **118** is in flow connection (and flow communication) with the sump module assembly **202**. Broken line **204d** denotes the location where the outlet **212** of the electric pump **120** is in flow connection (and flow communication) with the sump module assembly **202**. This broken line convention is used throughout the FIG. **2** illustration and is used in FIG. **2A**. However, this convention is simply for convenience in explaining the exemplary embodiment and is not intended to be structurally limiting in any manner. While the other components which have flow connections to the sump module assembly **202** are not technically considered part of the sump module assembly, these other components, such as the mechanical pump **118** and the electric pump **120**, are considered part of the overall hydraulic system **200**. Still, this convention of what components are part of what systems or subsystems remains somewhat arbitrary.

With continued referenced to FIGS. **2** and **2A**, hydraulic system **200** includes a main regulator valve **218**, main regulator by-pass valve **220**, control main valve **222**, exhaust back fill valve **224**, cooler **226**, filter **228**, lube regulator valve **230** (also referred to as a lube splitter valve), clutch trim valve **232**, accumulator **234**, solenoid **236**, solenoid **238** and accumulator **240**. It will be appreciated that these identified component parts and subassemblies of hydraulic system **200** are connected with various flow conduits and that pop off valves are strategically positioned to safeguard against excessive pressure levels. Further, downstream from the lube regulator valve **230** are illustrated elements which are intended to receive oil. The first priority of the available oil at the lube regulator valve **230** is for lubrication and cooling of bearings **244** and gears or other accessories which are in need of cooling and lubrication. The second priority, once the first priority has been satisfied, is to deliver oil to motor sleeve **246**.

The mechanical pump **118** is constructed and arranged to deliver oil to the main regulator valve **218** via conduit **250**.

One-way valve **248** is constructed and arranged for flow communication with conduit **250** and is positioned downstream from the mechanical pump **118**. Valve **248** is constructed and arranged to prevent backwards flow when the engine and (accordingly) the mechanical pump are OFF. Valve **248** includes a ball and spring arrangement set at a threshold of 5 psi. Branch conduit **254** provides a flow connection from conduit **250** to the main regulator by-pass valve **220**. The electric pump **120** is constructed and arranged to deliver oil to the main regulator by-pass valve **220** via conduit **256**.

The main regulator valve **218**, main regulator by-pass valve **220**, control main valve **222**, exhaust backfill valve **224**, lube regulator valve **230**, and clutch trim valve **232** each have a construction and arrangement which is best described, based on its construction and functionality, as a "spool valve". Each valve includes a valve body which defines an interior valve bore. Each valve also includes the use of a valve spool which is slidably disposed within the valve bore of the valve body. The selected cylindrical lands can be varied by diameter size, axial height, spacing, and relative location along the axis of the valve spool. The valve bore can also include sections with different diameters. Flow passages defined by the valve body connect to the various conduits, providing a predetermined and preselected arrangement of flow inputs and outputs, depending on incoming pressure levels and the positioning of the valve spool relative to the various flow passages.

In one style of spool valve, the valve spool acts against a biasing spring disposed at one end of the valve body. In another style (push-pull) fluid connections are provided at each end of the valve body. Pressurized fluid at one end with an exhaust or drain back at the opposite end moves the valve spool based on the pressure difference. One key to the particular style or construction is the number, spacing, axial height and diameter of each land of the spool valve. Another key to the particular style or construction is the number and location of the work ports which provide fluid communication. A more detailed description of this type of spool valve is provided in U.S. Pat. Nos. 7,392,892; 7,150,288; and 5,911,244. These three U.S. patent references are hereby incorporated by reference in their entirety as background technical information on the style and type of valve being used.

A partial, diagrammatic view of each of the six identified valves is provided by FIGS. **3-8**. The details of each valve in terms of its flow connections and the interconnecting fluid passages and conduits are described below. Described are the defined work ports for each valve in terms of the interconnecting conduits of hydraulic system **200**. As is illustrated in FIGS. **3-8** and as based in part on FIGS. **2** and **2A**, the various interconnecting conduits of hydraulic system **200** are in flow communication with selected work ports of these six valves. This is further described in the context of the description of each valve. A schematic, cross-sectional illustration of the six valves of FIGS. **3-8** is presented by FIGS. **3A-8A**, respectively. The FIG. **4** illustration uses the acronym HMEC which stands for hybrid module engine clutch.

Considering the diagrammatic form of FIGS. **2** and **2A**, it will be appreciated that the various flow connections and flow conduits may assume any one of a variety of forms and constructions so long as the desired oil flow can be achieved with the desired flow rate and the desired flow timing and sequence. The hydraulic system **200** description makes clear what type of oil flow is required between what components and subassemblies and the operational reason for each flow path. The hydraulic system **200** description which corresponds to what is illustrated in FIGS. **2** and **2A** is directed to what components and subassemblies are in oil flow commu-

nication with each other, depending on the hybrid system 100 conditions and the operational mode.

With continued to reference to FIGS. 2 and 2A and the various flow conduits which are illustrated, it will be noted that there are both “point-to-point” flow conduits and “point-to-conduit” flow conduits. There are a few flow conduit paths and connections which might be considered something of a “hybrid” of these two primary categories of flow conduit connections, as one would be able to recognize from the FIGS. 2 and 2A illustrations. A “point-to-point” flow conduit extends between two components, such as a pump, valve, solenoid, etc. A “point-to-conduit” flow conduit intersects another flow conduit and is flow coupled to a component. Table I as set forth below lists each flow conduit which is illustrated in FIGS. 2 and 2A.

The first column of Table I provides the reference number of the flow conduit. The second and third columns provide the reference numbers of the end points for that particular flow conduit. It is probably better or at least preferable to refer to the endpoints of each flow conduit rather than referring to the beginning and ending points as that might suggest a particular flow direction which would not necessarily be the case in every mode. In the event of any reverse or back flow terms such as “beginning” and “ending” become only relative terms. For this reason, the second and third columns of Table I should simply be understood as end points for the corresponding flow conduit.

Reference numbers 218, 220, 222, 224, 230 and 232 as used in FIGS. 2 and 2A and as listed in Table I, identify they hydraulic spool valves. Reference numbers 248, 249 and 287 identify one-way valves. Other non-conduit reference numbers as listed in Table I include solenoids 236 and 238, accumulators 234 and 240, cooler 226, filter 228, input clutch 289 and bearings 244. All other reference numbers in Table I identify a flow conduit of FIGS. 2 and 2A.

TABLE I

Conduit Paths/Connections		
Conduit	End Point	End Point
250	248	218
252	238	236
253	240	238
254	220	250
255	220	253
256	249	220
257	220	218
258	220	259
259	222	252
260	220	261
261	259	232
262	220	226
264	220	232
265	220	218
266	220	222
267	259	264
268	218	222
270	218	262
272	268	232
274	268	259
275	218	268
276	222	224
278	276	232
280	222	244
282	280	230
284	226	228
285	228	230
286	262	287
288	232	289
290	236	232
292	232	234

TABLE I-continued

Conduit Paths/Connections		
Conduit	End Point	End Point
294	232	288
296	230	282

Each of the six hydraulic spool valves of FIG. 2A are separately illustrated as enlarged diagrammatic illustrations in FIGS. 3-8. These drawings show the ports and connections of each valve in a manner corresponding to FIG. 2 and consistent with what is set forth in Table I. Corresponding reference numbers for the connecting flow conduits are used. In FIGS. 3A-8A, a schematic illustration, in full section, of each of the six hydraulic spool valves is provided in order to show the interior spool construction of each valve. The FIG. 3A illustration of valve 218 corresponds to the spool valve 218 which is illustrated in FIG. 3. Similarly, FIGS. 4A-8A correspond to FIGS. 4-8, respectively.

Before describing each of the three modes of operation applicable to hydraulic system 200, the relationship between and some of the construction details regarding the mechanical pump 118 and the electric pump 120 will be described. Understanding a few of the pump basics should facilitate a better understanding of the three modes of operation selected for further discussion regarding the overall hydraulic system.

Referring now to FIG. 9, a front perspective view is provided which includes a partial cross section through the hybrid module 104 from the perspective of the engine engagement side 300 of the hybrid module 104. On the engine engagement side 300, the hybrid module 104 has the mechanical pump 118 with a pump housing 302 that is secured to the hybrid module housing 304. A pump drive gear 306 which is secured to an input shaft 308 is used to drive the mechanical pump 118. The drive gear 306 in one example is secured to the input shaft 308 via a snap ring and key arrangement, but it is contemplated that the drive gear 306 can be secured in other manners. The mechanical pump 118 in conjunction with the electric pump 120 supplies fluid for lubrication, hydraulics, and/or cooling purposes to the hybrid module 104. By incorporating the electric pump 120 in conjunction with the mechanical pump 118, the mechanical pump 118 can be sized smaller, which in turn reduces the required space it occupies as well as reduces the cost associated with the mechanical pump 118. Moreover, the electric pump 120 facilitates lubrication even when the engine 102 is OFF. This in turn facilitates electric-only operating modes as well as other modes of the hybrid system 100. Both the mechanical pump 118 and the electric pump 120 recirculate fluid from the sump 116. The fluid is then supplied to the remainder of the hybrid module 104 via holes, ports, openings and other passageways traditionally found in transmissions for circulating oil and other fluids. A clutch supply port 310 supplies oil that hydraulically applies or actuates the clutch 114. In the illustrated embodiment, the clutch supply port 310 is in the form of a tube, but is envisioned it can take other forms, such as integral passageways within the hybrid module 104, in other examples.

The operation of the hybrid system 100 involves or includes various operational modes or status conditions, also referred to herein as “system modes” or simply “modes”. The principal hybrid system 100 modes are summarized in Table II which is provided below:

11

TABLE II

SYSTEM MODES				
Mode	Clutch	Motor	PTO	Transmission
Engine Start	Engaged	Motor	Inoperative	Neutral
Charge Neutral	Engaged	Generator	Inoperative	Neutral
eAssist Propulsion	Engaged	Motor	Inoperative	In Gear
eDrive	Disengaged	Motor	Inoperative	In Gear
Propulsion with Charge	Engaged	Generator	Inoperative	In Gear
Regeneration	Disengaged	Generator	Inoperative	In Gear
Charging	Disengaged	Generator	Inoperative	In Gear
No Charge Braking	Engaged	N/A	Inoperative	In Gear
PTO	Engaged	N/A	Operative	Neutral
ePTO	Disengaged	Motor	Operative	Neutral

During an initialization and/or startup mode, the electric pump **120** is activated by the transmission/hybrid control module **148** so as to circulate fluid through the hybrid module **104**. The electric pump **120** receives its power from the energy storage system **134** via the inverter **132** (FIG. 1). Once sufficient oil pressure is achieved, the clutch **114** is engaged. At the same time or before, the PTO is inoperative or remains inoperative, and the transmission **106** is in neutral or remains in neutral. With the clutch **114** engaged, the eMachine **112** acts as a motor and in turn cranks the engine **102** in order to start (i.e., spin/crank) the engine. When acting like a motor, the eMachine **112** draws power from the energy storage system **134** via the inverter **132**. Upon the engine **102** starting, the hybrid system **100** shifts to a charge neutral mode in which the fuel is on to the engine **102**, the clutch **114** is engaged, and the eMachine **112** switches to a generator mode in which electricity generated by its rotation is used to charge the energy storage modules **136**. While in the charge neutral mode, the transmission remains in neutral.

From the charge neutral mode, the hybrid system **100** can change to a number of different operational modes. The various PTO operational modes can also be entered from the charge neutral mode. As should be understood, the hybrid system is able to move back and forth between the various operational modes. In the charge neutral mode, the transmission is disengaged, that is, the transmission is in neutral. Referring to Table II, the hybrid system **100** enters a propulsion assist or eAssist propulsion mode by placing the transmission **106** in gear and having the eMachine **112** act as a motor.

During the eAssist propulsion mode, a PTO module is inoperative and the fuel to the engine **102** is on. In the eAssist propulsion mode, both the engine **102** and the eMachine **112** work in conjunction to power the vehicle. In other words, the energy to power the vehicle comes from both the energy storage system **134** as well as the engine **102**. While in the eAssist propulsion mode, the hybrid system **100** can then transition back to the charge neutral mode by placing the transmission **106** back into neutral and switching the eMachine **112** to a generator mode.

From the eAssist propulsion mode, the hybrid system **100** can transition to a number of different operational states. For instance, the hybrid system **100** can transition from the eAssist propulsion mode to an electrical or eDrive mode in which the vehicle is solely driven by the eMachine **112**. In the eDrive mode, the clutch **114** is disengaged, and the fuel to the engine **102** is turned off so that the engine **102** is stopped. The transmission **106** is placed in a driving gear. As the eMachine **112** powers the transmission **106**, the PTO module is inoperative. While in the eDrive mode, the electric pump **120**

12

solely provides the hydraulic pressure for lubricating the hybrid module **104** and controlling the clutch **114**, because the mechanical pump **118** is not powered by the stopped engine **102**. During the eDrive mode, the eMachine **112** acts as a motor. To return to the eAssist propulsion mode, the electric pump **120** remains on to provide the requisite back pressure to engage the clutch **114**. Once the clutch **114** is engaged, the engine **102** is spun and fuel is turned on to power the engine **102**. When returning to the eAssist propulsion mode from the eDrive mode, both the eMachine **112** and the engine **102** drive the transmission **106**, which is in gear.

The hybrid system **100** also has a propulsion charge mode, a regenerative braking charge mode, and a compression or engine-braking mode. The hybrid system **100** can transition to the propulsion charge mode from the charge neutral mode, the eAssist propulsion mode, the regenerative braking charge mode, or the engine-braking mode. When in the propulsion charge mode, the engine **102** propels the vehicle while the eMachine **112** acts as a generator. During the propulsion charge mode, the clutch **114** is engaged such that power from the engine **102** drives the eMachine **112** and the transmission **106**, which is in gear. Again, during the propulsion charge mode, the eMachine **112** acts as a generator, and the inverter **132** converts the alternating current produced by the eMachine **112** to direct current, which is then stored in the energy storage system **134**. In this mode, the PTO module is in an inoperative state. While in the propulsion charge mode, the mechanical pump **118** generally handles most of the oil pressure and lubricant needs, while the electric pump **120** provides eMachine cooling. The load between the mechanical **118** and electric **120** pumps is balanced to minimize power loss.

The hybrid system **100** can transition to a number of operational modes from the propulsion charge mode. For example, the hybrid system **100** can transition to the charge neutral mode from the propulsion charge mode by placing the transmission **106** in neutral. The hybrid system **100** can return to the propulsion charge mode by placing the transmission **106** into gear. From the propulsion charge mode, the hybrid system **100** can also switch to the propulsion assist mode by having the eMachine **112** act as an electric motor in which electricity is drawn from the energy storage system **134** to the eMachine **112** such that the eMachine **112** along with the engine **102** drive the transmission **106**. The regenerative charge mode can be used to recapture some of the energy that is normally lost during braking. The hybrid system **100** can transition from the propulsion charge mode to the regenerative charge mode by simply disengaging the clutch **114**. In some instances, it may be desirable to use the engine-braking mode to further slow down the vehicle and/or to reduce wear of the brakes. Transitioning to the engine-braking mode can be accomplished from the propulsion charge mode by turning off the fuel to the engine **102**. During the engine-braking mode, the eMachine **112** acts as a generator. The hybrid system **100** can return to the propulsion charge mode by turning back on the fuel to the engine **102**. Simply disengaging the clutch **114** will then switch the hybrid system **100** to the regenerative charging mode.

The hybrid system **100** is able to conserve energy normally lost during braking by utilizing the regenerative braking/charge mode. During the regenerative charge mode, the clutch **114** is disengaged. The eMachine **112** acts as a generator while the transmission **106** is in gear. The power from the wheels of the vehicle is transferred through the transmission **106** to the eMachine **112**, which acts as a generator to reclaim some of the braking energy and in turn helps to slow down the vehicle. The recovered energy via the inverter **132** is

13

stored in the energy storage system **134**. As noted in Table II above, during this mode the PTO module is inoperative.

The hybrid system **100** can transition from the regenerative charge mode to any number of different operational modes. For instance, the hybrid system **100** can return to the propulsion assist mode by engaging the clutch **114** and switching the eMachine **112** to act as a motor. From the regenerative charge mode, the hybrid system **100** can also return to the propulsion charge mode by engaging the clutch **114**, and switching the eMachine **112** to the generator role. The hybrid system **100** can also switch to the engine-braking mode from the regenerative charge mode by turning off the fuel to the engine **102** and engaging the clutch.

In addition to the regenerative braking mode, the hybrid system **100** can also utilize the engine-braking mode in which compression braking of the engine **102** is used to slow down the vehicle. During the engine braking mode, the transmission **106** is in gear, the PTO module is inoperative, and the eMachine **112** is acting as a generator so as to recover some of the braking energy, if so desired. However, during other variations of the engine-braking mode, the eMachine **112** does not need to act as a generator such that the eMachine **112** draws no power for the energy store system module **134**. To transmit the energy from the vehicle's wheels, the engine clutch **114** is engaged and the power is then transmitted to the engine **102** while the fuel is off. In another alternative, a dual regenerative and engine braking mode can be used in which both the engine **102** and the eMachine **112** are used for braking and some of the braking energy from the eMachine **112** is recovered by the energy storage system module **134**.

The hybrid system **100** can transition from the engine-braking mode to any number of different operational modes. As an example, the hybrid system **100** can switch from the engine-braking mode to the propulsion assist mode by turning on the fuel to the engine **102** and switching the eMachine **112** to act as an electric motor. From the engine-braking mode, the hybrid system **100** can also switch to the propulsion charge mode by turning back on the fuel to the engine **102**. In addition, the hybrid system **100** can switch from the engine-braking mode to the regenerative charge mode by turning on the fuel to the engine **102** and disengaging the clutch **114**.

When the PTO is used, the vehicle can be stationary or can be moving (e.g., for refrigeration systems). From the charge neutral mode, the hybrid system **100** enters a PTO mode by engaging the PTO. While in the PTO mode, the clutch **114** is engaged such that power from the engine **102** is transmitted to the now-operative PTO. During this PTO mode, the eMachine **112** acts as a generator drawing supplemental power from the engine **102** and transferring it via the inverter **132** to the energy storage system module **134**. At the same time, the transmission **106** is in neutral so that the vehicle can remain relatively stationary, if desired. With the PTO operative, the ancillary equipment, such as the lift buckets, etc., can be used. The hybrid system **100** can return to the charge neutral mode by making the PTO inoperative.

During the PTO mode, the engine **102** is constantly running which tends to waste fuel as well as create unnecessary emissions in some work scenarios. Fuel can be conserved and emissions reduced from the hybrid system **100** by switching to an electric or ePTO mode of operation. When transitioning to the ePTO mode, the clutch **114**, which transmits power from the engine **102**, is disengaged and the engine **102** is stopped. During the ePTO mode, the eMachine **112** is switched to act as an electric motor and the PTO is operative. At the same time, the transmission **106** is in neutral and the engine **102** is stopped. Having the engine **102** turned off reduces the amount of emissions as well as conserves fuel.

14

The hybrid system **100** can return from the ePTO mode to the PTO mode by continued operation of the electric **120** pump, engaging the clutch **114** and starting the engine **102** with the eMachine **112** acting as a starter. Once the engine **102** is started, the eMachine **112** is switched over to act as a generator and the PTO is able to operate with power from the engine **102**.

With the operation or system modes of hybrid system **100** (see Table II) in mind, the hydraulic system **200** is now further described in the context of three modes of operation. These three modes include an Electric Mode (eMode), a Transition Mode, and a Cruise Mode. From the perspective of the status and conditions of hydraulic system mode, the eMode conditions are diagrammatically illustrated in FIG. **10**. The Transition Mode conditions are diagrammatically illustrated in FIG. **11**. The Cruise Mode conditions are diagrammatically illustrated in FIG. **12**.

Referring first to FIG. **10**, in the eMode condition, as represented by hydraulic system **200a**, the engine and clutch are each in an "OFF" condition, and each solenoid **236** and **238** is an "OFF" condition. The electric pump **120** provides one hundred percent (100%) of the oil flow to the main regulator valve **218**. With solenoid **238** in an "OFF" condition, there is no solenoid signal to the main regulator by-pass valve **220** and this component is also considered as being in an "OFF" condition. In the exemplary embodiment, the main pressure is "knocked down" to 45 psi due to using only the electric pump **120** and considering its performance limitations. Any lube/cooling flow to the cooler **226** is the result of main regulator valve **218** overage.

Referring now to FIG. **11**, in the Transition Mode condition as represented by hydraulic system **200b**, the engine may be in either an "ON" or "OFF" condition, the clutch is in an "ON" condition, solenoid **238** is "OFF", and solenoid **236** is "ON". The electric pump **120** and the mechanical pump **118** can supply a flow of oil to the main regulator valve **218**. The knockdown is removed and the main pressure is 90 psi. Any lube/cooling flow to the cooler **226** is the result of main regulator valve **218** overage.

Referring now to FIG. **12**, in the Cruise Mode, as represented by hydraulic system **200c**, the engine and clutch are each in an "ON" condition, and solenoid **236** is in an "ON" condition. The main regulator by-pass valve **220** is held in the "ON" (applied) position by a hydraulic latch. This hydraulic latch has a signal pressure which comes from the clutch trim valve **232** and the latch is only active when both the clutch trim valve **232** and the main regulator by-pass valve **220** are in the "ON"/applied position. In this condition, the mechanical pump **118** provides one hundred percent (100%) of the oil flow to the main regulator valve **218** and to the clutch control hydraulics. The electric pump **120** provides supplemental cooler flow (or what may be referred to as cooler flow "boost"). The flow to the cooler **226** is by way of the main regulator valve **218** overage and supplemented by flow from the electric pump **120**. To initially turn the main regulator by-pass valve **220** to the "ON" condition, solenoid **238** is briefly turned on. Once the main regulator by-pass valve **220** is in the ON condition the hydraulic latch becomes active and solenoid **238** is no longer required to hold the main regulator by-pass valve **220** in the "ON" position. Also, once the main regulator by-pass valve **220** is on the ON position, the output of solenoid **238** is connected to the base of the main regulator valve **218** and is now used as boost pressure. With this variable solenoid **238** supplying boost pressure, the main regulator valve **218** now produces a variable main pressure between 45 and 225 psi depending upon the pressure of solenoid **238**, see FIG. **15**.

15

The three modes which have been described and illustrated in FIGS. 10-12 have been identified in conjunction with hydraulic systems 200a, 200b, and 200c, respectively. This numbering scheme of letter suffixes is representative of the fact that the hardware, components, subassemblies, and conduits of hydraulic system 200 do not change with the different modes of operation. However, the operational status, the various ON/OFF conditions, etc. of the hardware, components, and subassemblies may change, depending on the particular item and the specific mode of operation.

While the three described modes for the hydraulic system 200 are based in part on the status or conditions of the engine, these modes are also based in part on the ON/OFF status of the referenced hardware, components, and subassemblies, including the mechanical pump 118 and the electric pump 120. The mechanical pump 118 is directly connected to the engine 102 such that when the engine is ON, the mechanical pump 118 is ON. When the engine 102 is OFF, the mechanical pump 118 is OFF. When ON, the mechanical pump 118 delivers oil to the entire hydraulic system. Any overage from the main regulator valve 218 is delivered to the cooler 226.

The ON/OFF status of the electric pump 120 and the speed of the electric pump 120 are controlled by the electronics of the hybrid module 104. The electric pump 120 delivers oil either to the hydraulic system 200 and/or to the cooler 226. When the mechanical pump 118 is either OFF or when its delivery of oil is insufficient, the electric pump 120 delivers oil to the hydraulic system. When the delivery of oil from the mechanical pump is sufficient, the electric pump 120 is able to be used for delivery of oil to the cooler for lube and motor cooling.

Reference has been made to the knocked down lower pressure level for certain operational modes. This knocked down pressure is associated with operation of the electric pump 120. Considering the various pressure levels and flow rates, the main pressure of the mechanical pump 118 is 45-225 psi. The main pressure of the electric pump 120 is 45 or 90 psi. For lube and cooling, the first 5.0 lpm of flow at approximately 30 psi is used for lube. Any excess flow up to approximately 15.0 lpm is delivered to the motor cooling sleeve 246. A maximum of 50 psi for the lube/cooling function is attained only after the motor cooling sleeve 246 is filled with oil. The clutch applied pressure will be nearly equal to main pressure with a slight pressure drop (0-5 psi) due to the clutch passageways.

With continued reference to FIG. 2, there are specific portions of the disclosed hydraulic system 200 which denote changes and improvements over earlier designs and embodiments. One improvement is that separate suction filters 298 and 299 are incorporated into each pump inlet conduit 206 and 208, respectively. Each suction filter 298 and 299 is positioned adjacent the inlet opening 206a and 208a of each conduit, respectively.

Another improvement is directed to reconfigured logic for main regulator by-pass valve 220. The flow circuitry and logic of control main valve 222 is also modified over earlier embodiments for increased consistency. A further improvement is adding a control main valve lube bleed by the addition of flow conduit 280. A further improvement relates to the exchange of an ON/OFF solenoid with a variable bleed sole-

16

noid (VBS) which is multiplexed to operate between the logic valve 220 and main boost. A still further improvement is directed to the main regulator valve 218 and a main modulation boost when the logic valve 220 is applied.

Referring now to the functionality of the mechanical pump 118 and the electric pump 120, the mechanical pump 118 is connected to the engine input with a 1:1 drive ratio. As such, when the engine is ON the mechanical pump 118 is ON. When the engine is OFF, the mechanical pump is OFF. The mechanical pump 118 directly feeds the main regulator valve 218. The first lube priority is to the valve body and clutch needs. The second lube priority is for the cooler and the lube circuit. The main pressure relief is set at 400 psi.

The speed and flow of the electric pump 120 are dictated by the engine software and system programming, specifically by the transmission control module software. The electric pump 120 supplies oil to either the main regulator valve or bypasses to the cooler 226 and lube circuit. The referenced "lube circuit" is generally referred to as reference 244 (bearings, etc.). The operation of the electric pump 120 is dependent on the hydraulic mode. Further, the electric pump 120 is able to supply oil or lube to cooler flow when the lube delivery by the mechanical pump 118 is not adequate. The electric pump 120 pressure relief is set at 120 psi.

The hydraulic modes of operation of hydraulic system 200 include, as noted above, eMode (FIG. 10), Transition Mode (FIG. 11), and Cruise Mode (FIG. 12). The flow circuit and flow paths for each hydraulic mode are illustrated in FIGS. 10-12, noting the drawing key which identifies the nature of the flow based on the graphic cross-hatching. In the eMode, the engine is OFF and the clutch is OFF. All of the hydraulics are supplied by the electric pump 120. In the Transition Mode, the engine transitions from OFF to ON and the clutch is applied. Both the mechanical pump 118 and the electric pump 120 supply lube to the main regulator valve. In the Cruise Mode, the engine is ON and the clutch is ON. The mechanical pump 118 supplies the hydraulics for clutch control. The electric pump 120 provides the hydraulics for the cooler flow "boost".

With continued reference to FIGS. 10-12, it is noted that in the eMode of FIG. 10, both solenoids 236 and 238 are hydraulically OFF. The main knock down pressure is 45 psi. Any flow or supply overage from the main is directed to the cooler. In the Transition Mode of FIG. 11, the trim solenoid 236 is hydraulically ON and the logic solenoid 238 is hydraulically OFF. Both the mechanical pump 118 and the electric pump 120 supply flow to the main regulator valve 218. Both pumps are set an operating pressure of 90 psi (knockdown exhausted). Any lube overage is directed to the cooler 226. In the Cruise Mode of FIG. 12, solenoid 236 is hydraulically ON and solenoid 238 is variable. The lube from the electric pump 120 is supplied to the cooler. The mechanical pump 118 supplies lube to the main regulator valve 218. The main regulator pressure is torque dependent and between 45 psi and 225 psi (knockdown and boost). The electric pump pressure is flow dependent and operates between 0 and 70 psi. Table III provides a quick reference for some of the operational parameters for each operational mode.

TABLE III

Mode Chart Reference Table								
Mode	ePump	ePump Pressure	ePump Output	mPump	mPump Pressure	Clutch	Main Knockdown	Main Boost
eMode	On	45 psi	Main Reg	Onn	—	Open	Pressurized	Exhausted
Transition	On	90 psi	Main Reg	On/Off	90 psi	Applying/ Applied	Exhausted	Exhausted
Cruise	On/Off	0-70 psi	To cooler	On	45-225 psi	Applied	Pressurized	Variable Pressure

Regarding some of the specifics of main regulator valve **218**, it is a dual regulation valve with both exhaust and overage to cooler **226**. For the knockdown and boost aspects, the electric pump pressure is either 45 psi or 90 psi. The mechanical pump pressure is a variable between 45 psi and 225 psi. A lower rate spring is used so that there is less force or pressure acting against the flow fluctuations. The three modes operation relative to the main regulator valve **218** as described above, at least in part, are diagrammatically illustrated in FIGS. **13**, **14** and **15**.

Regarding some of the specifics of the control main valve **222**, this is a single regulation valve which regulates at 110 psi and routes any lube overage to the exhaust backfill valve **224**. There are two by-pass orifices which handle lube flow from the main regulator valve **218** and direct lube in the direction of the downstream lube requirements (bearings **244**). Regarding some of the specifics of the clutch trim valve **232**, this valve interfaces with solenoid **236** and accumulator **234**. The regulation pressure ranges between 195 psi and 225 psi.

The lube regulator valve **230** is a dual regulation valve which assists in providing lube to the eMotor sleeve **246** as a second priority and to the lube requirements (bearings **244**) as a first priority. Once the lube requirements are met, any additional lube which is available is directed to the motor sleeve **246**. The by-pass orifice provides lube flow under low flow conditions for failure mode protection.

The main regulator by-pass valve **220**, also called the logic valve, directs flow in a number of different ways. The lube from the electric pump **120** is directed to the main regulator valve **218** and to the cooler **226**. The other states or functions of lube control and management include knockdown (pressurized/exhaust), boost (exhausted/pressurized), latch (exhausted/pressurized), and pressure switch (exhausted/pressurized).

The solenoid **238** strokes valve **220** from installed to applied. If the clutch is OFF then the solenoid is needed to hold the valve at the applied position. If the clutch is ON, then a latch status holds the valve at the applied position. In this ON condition, the solenoid **238** is not needed to hold the valve at the applied position and the solenoid, via multiplexing, is available for the main modulation boost. The logic valve **220** de-strokes when the latch is exhausted by the clutch trim valve **232**. In terms of any failure mode or status, one would be when the logic valve electrically fails to go to the valve applied position. In this state, the electric pump **120** lube goes to the cooler **226**. Since there is a high main pressure, any risk of a low pressure failure mode is removed. FIGS. **16** and **17** provide graphic illustrations of the main regulator by-pass valve **220** in the installed position (eMode) and in the applied position (Cruise Mode). The labels on the ports and conduits are consistent with what has been described above.

Regarding some of the specifics of the exhaust backfill valve **224**, this valve manages the supply of low pressure oil to the clutch **289**. The setpoint is at 2 psi and the use of this low

pressure lube helps to keep air out of the clutch and facilitates fill time consistency. One-way valve **287** (see FIG. **2**) which is a cooler pressure relief valve has a set point of 140 psi and is based on a ball and spring construction.

In addition to suction filters **298** and **299** which are associated with the pump inlets, a third filter **228** is included as a lube filter which is downstream from the cooler. The lube filter **228** is a low micron filter. Filters **298** and **299** share a common body but are separate hydraulically. The lube filter **228** is a spin-on filter.

Some of the other features of hydraulic system **200** include the design and construction of the interface of the normally applied clutch. In the event of an electrical failure with the engine On, the system defaults to a high main and the clutch is applied. With the engine Off, the system defaults to neutral (no starter). In effect there are two pressure switches corresponding to the logic valve **220** and the clutch trim **232**. Both pumps **118** and **120** are constructed and arranged for one-way flow so as to prevent back flow and leakage around the pumps.

Another feature of hydraulic system **200** is the addition (new design) of a main modulation control scheme which relies in part on the addition of VBS solenoid **238** and the multiplexing (modulation) of that solenoid. By controlling the main pressure at a reduced level, the fuel economy and reliability are improved. The pressure is controlled by the multiplexed VBS solenoid **238** in order to maintain adequate clutch pressure based on torque requirements. The overall system cost is reduced by this multiplexing of valves and solenoids. The disclosed hydraulic system **200** provides a reduced pressure schedule based on torque to reduce spin losses (improves fuel economy) and increase cooler flow (improves reliability). By integrating this reduced pressure schedule with the multiplexing of solenoids and valves, cost is reduced.

In the FIGS. **2** and **2A** illustrations, it will be seen that only two solenoids **236** and **238** are used to control pressure. In fact, only two solenoids are able to be used since the hybrid control module (HCM) only includes two drivers. When multiplexing the VBS solenoid **238**, it can be used to get different pressure levels, including a reduced pressure for certain conditions and applications. Reducing the pressure results in a reduced pump load on the electric pump **120**. When the electric pump **120** has a lower load, then the electric pump is not working as hard. A lower pressure requirements means that there is more lube to the bearings and cooler.

One of the characteristics of hydraulic system **200** as noted above is the design and construction facilitated by multiplexing and the overall main modulation control scheme which decreases the pump work. A high pressure is required in order to keep the clutch from slipping at high torque. However, as the torque level changes, pressure adjustments are possible. The option, as presented here, is to adjust the pressure based on the torque level of the gearbox.

19

While the preferred embodiment of the invention has been illustrated and described in the drawings and foregoing description, the same is to be considered as illustrative and not restrictive in character, it being understood that all changes and modifications that come within the spirit of the invention are desired to be protected.

The invention claimed is:

1. A hydraulic system for a hybrid electrical vehicle comprising:

- a sump containing hydraulic fluid;
- a main regulator valve constructed and arranged in flow communication with said sump;
- a main regulator by-pass valve constructed and arranged in flow communication with said sump;
- first and second control solenoids wherein said first control solenoid is a variable bleed solenoid; and
- a control module for managing fluid flow of said hydraulic system, wherein said control module is constructed and arranged for multiplexing of said variable bleed solenoid, wherein said multiplexing is applied for said variable bleed solenoid to either hold the main regulator by-pass valve at an applied position or make the variable bleed solenoid available for main boost.

2. The hydraulic system of claim 1 wherein the hybrid electric vehicle has three operational modes associated with the hydraulic system, including an eMode, a transition mode and a cruise mode.

3. The hydraulic system of claim 1 which further includes a mechanical pump constructed and arranged in flow communication with said sump and in flow communication with said main regulator valve for delivering hydraulic fluid from said sump to said main regulator valve.

4. The hydraulic system of claim 3 which further includes an electric pump constructed and arranged in flow communication with said sump and in flow communication with said main regulator by-pass valve for delivering hydraulic fluid from said sump to said main regulator by-pass valve.

5. The hydraulic system of claim 4 wherein said control module is constructed and arranged for managing the operational status of said mechanical pump and of said electric pump based on an operational mode of the hybrid electric vehicle.

6. The hydraulic system of claim 1 wherein said first control solenoid is constructed and arranged in flow communication with said main regulator by-pass valve.

7. The hydraulic system of claim 1 which further includes a clutch trim valve.

8. The hydraulic system of claim 7 wherein said second control solenoid is constructed and arranged in fluid communication with said clutch trim valve.

9. The hydraulic system of claim 1 which further includes a lube bleed conduit in flow communication with a control main valve.

10. The hydraulic system of claim 1 wherein said control module is a hybrid control module with two drivers.

11. The hydraulic system of claim 10 wherein one of said two drivers corresponds to said variable bleed solenoid and the other of said two drivers corresponds to said second control solenoid.

12. The hydraulic system of claim 1 wherein said control module is constructed and arranged to adjust a pressure level of said hydraulic system based on a gearbox torque value.

13. A hydraulic system for a hybrid electrical vehicle comprising:

- a sump containing hydraulic fluid;
- a main regulator valve constructed and arranged in flow communication with said sump;

20

a main regulator by-pass valve constructed and arranged in flow communication with said sump;

a hybrid control module; and

a control solenoid constructed and arranged in flow communication with said main regulator by-pass valve wherein said hybrid control module is constructed and arranged for the multiplexing of said control solenoid, wherein said multiplexing is applied for said control solenoid to either hold the main regulator by-pass valve at an applied position or make the control solenoid available for main boost.

14. The hydraulic system of claim 13 wherein said control solenoid is a variable bleed solenoid.

15. The hydraulic system of claim 14 wherein the hybrid electric vehicle has three operational modes associated with the hydraulic system, including an eMode, a transition mode and a cruise mode.

16. The hydraulic system of claim 15 wherein said hybrid control module is constructed and arranged with two drivers.

17. The hydraulic system of claim 16 wherein one of said two drivers corresponds to said variable bleed solenoid and the other of said two drivers corresponds to a second control solenoid.

18. The hydraulic system of claim 17 wherein said hybrid control module is constructed and arranged to adjust a pressure level of said hydraulic system based on a gearbox torque value.

19. A hydraulic system for a hybrid electrical vehicle comprising:

- a sump containing hydraulic fluid;
- a main regulator valve constructed and arranged in flow communication with said sump;
- a main regulator by-pass valve constructed and arranged in flow communication with said sump;
- first and second control solenoids wherein said first control solenoid is a variable bleed solenoid;
- a mechanical pump in flow communication with said sump;
- an electric pump in flow communication with said sump; and
- a control module for managing the operational status of each pump, wherein said control module is constructed and arranged for the multiplexing of said variable bleed solenoid, wherein said multiplexing is applied for said variable bleed solenoid to either hold the main regulator by-pass valve at an applied position or make the variable bleed solenoid available for main boost.

20. The hydraulic system of claim 19 wherein the hybrid electric vehicle has three operational modes associated with the hydraulic system, including an eMode, a transition mode and a cruise mode.

21. The hydraulic system of claim 19 wherein said first control solenoid is constructed and arranged in flow communication with said main regulator by-pass valve.

22. The hydraulic system of claim 19 which further includes a clutch trim valve.

23. The hydraulic system of claim 22 wherein said second control solenoid is constructed and arranged in fluid communication with said clutch trim valve.

24. A hydraulic system for a hybrid electrical vehicle comprising:

- a sump containing hydraulic fluid;
- a main regulator valve constructed and arranged in flow communication with said sump;
- a main regulator by-pass valve constructed and arranged in flow communication with said sump;

21

first and second control solenoids wherein said first control solenoid is a variable bleed solenoid;
 a clutch trim valve; and
 wherein said second control solenoid is constructed and arranged in fluid communication with said clutch trim valve.

25. The hydraulic system of claim **24** wherein the hybrid electric vehicle has three operational modes associated with the hydraulic system, including an eMode, a transition mode and a cruise mode.

26. The hydraulic system of claim **24** wherein said control module is constructed and arranged for managing the operational status of said mechanical pump and of said electric pump based on an operational mode of the hybrid electric vehicle.

27. The hydraulic system of claim **24** wherein said first control solenoid is constructed and arranged in flow communication with said main regulator by-pass valve.

28. A hydraulic system for a hybrid electrical vehicle comprising:

a sump containing hydraulic fluid;
 a main regulator valve constructed and arranged in flow communication with said sump;
 a main regulator by-pass valve constructed and arranged in flow communication with said sump;
 first and second control solenoids wherein said first control solenoid is a variable bleed solenoid;

22

a clutch trim valve, wherein said second control solenoid is constructed and arranged in fluid communication with said clutch trim valve; and
 a control module for managing fluid flow of said hydraulic system, wherein said control module is constructed and arranged for multiplexing of said variable bleed solenoid.

29. A hydraulic system for a hybrid electrical vehicle comprising:

a sump containing hydraulic fluid;
 a main regulator valve constructed and arranged in flow communication with said sump;
 a main regulator by-pass valve constructed and arranged in flow communication with said sump;
 first and second control solenoids wherein said first control solenoid is a variable bleed solenoid;
 a clutch trim valve, wherein said second control solenoid is constructed and arranged in communication with said clutch trim valve;
 a mechanical pump in flow communication with said sump;
 an electric pump in flow communication with said sump; and
 a control module for managing the operational status of each pump, wherein said control module is constructed and arranged for the multiplexing of said variable bleed solenoid.

* * * * *